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Comparison Of The Effectiveness Of Alternative Ferrate (vi) Synthesis Formulas As Disinfectants For Wastewater And River Water

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COMPARISON OF THE EFFECTIVENESS OF ALTERNATIVE FERRATE (VI) SYNTHESIS FORMULAS AS DISINFECTANTS FOR WASTEWATER AND RIVER WATER

by

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ABSTRACT

Ferrate (VI) has been studied as an alternative chemical to disinfect water and wastewater in recent years. The disinfection effectiveness of two different wet oxidation ferrate (VI) synthesis formulas in wastewater and Econlockhatchee River water was evaluated. Ferrate (VI) is synthesized by addition of ferric chloride to a mixture of sodium hydroxide and calcium hypochlorite (refer to U.S. Patent 6,790,429). One ferrate (VI) synthesis formula uses below the stoichiometric requirement of hypochlorite (Low Chlorine Formula) while the other ferrate (VI) synthesis formula uses more than the stoichiometric requirement of hypochlorite (Standard Chlorine Formula). For applications requiring low chlorine residual effluent quality, the Low Chlorine Formula intuitively is a more suitable disinfectant than the Standard Formula. For applications where chlorine residual is of little or no significance, the Standard Formula is logically a more suitable disinfectant due to lower production cost and production of higher ferrate (VI) concentrations than the Low Chlorine Formula. The total chlorine concentration, unfiltered and filtered ferrate (VI) concentration, and dissolved organic carbon concentration before and after treatment using both ferrate (VI) formulas in wastewater and Econ River water was measured at a contact time of 30 minutes. Disinfection capabilities were measured by comparing the quantity of Heterotrophic bacteria, Total Coliform, *Escherichia coli*, and Enterococcus bacteria pre-ferrate (VI) to post-ferrate (VI) at dosages of 2, 4, and 7.5 mg/L as ferrate (VI) using both ferrate (VI) formulas. The rate of disappearance of both ferrate (VI) formulas in wastewater at an unadjusted pH and pH of 6.0-6.35 was determined. In addition the total oxidant absorbance and total chlorine concentration were measured over a 30-minute period. Both ferrate (VI) formulas were effective at inactivating Total Coliform, *E. Coli*, Enterococcus, and heterotrophic bacteria at a 30-minute contact time and lowering DOC concentrations in Econlockhatchee River water and secondary wastewater. The Standard Formula demonstrated better disinfection at lower dosages than the Low Chlorine Formula. In both ferrate (VI) formulas, there was a presence of an instantaneous demand of ferrate (VI) and a first-order reaction rate of ferrate (VI) over 30 minutes. The chlorine residual of 7.5 mg/L ferrate (VI) dose in wastewater at a 30-minute contact time was 0.2 to 0.6 mg/L Cl_2 for the Low Chlorine Formula and 0.8 to 1.4 mg/L Cl_2 for the Standard Formula. These experiments indicate that both ferrate (VI) formulas can serve as effective environmentally friendly disinfectants for wastewater and Econ River water.

This research is dedicated to the individuals who have helped me reach this dream. My loving father, mother, and older sister have been endless supporters, motivators, and inspirations in my life. My father made all my dreams a possibility and encourages me to make them come true. My mother believed in me and reminded me to enjoy each and everyday. My sister keeps me grounded and is always there for me no matter what.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

%- percent
abs- absorbance
avg- average
BDL- Below Detection Limit
CFU- colony forming units
cm- centimeter
conc- concentration
DBP- disinfection byproducts
DPD- N, N diethyl-p-phenylenediamine
DOC- dissolved organic carbon
ECD- Electron-Capture Detection
E. coli- Escherichia coli
Econ - Econlockhatchee River
EPA- Environmental Protection Agency
F.A.C- Florida Administrative Code
FDEP- Florida Department of Environmental Protection
Filt- filtered
HAA- haloacetic acids
KHP- potassium hydrogen phthalate
L- liter
M- molarity (moles per liter)
mg- milligram
min- minute
mL- milliliter
µm- micrometer
MPN- most probable number
nd- not detectable
nm- nanometer
obs- observed
rpm- revolutions per minute
THM- trihalomethane
THMFP- Trihalomethane formation potential
TOC- total organic carbon
Unf- unfiltered
UV- ultraviolet
V- volt

CHAPTER 1: GENERAL INTRODUCTION

Disinfection is an important process in wastewater treatment. Ferrate (VI) has been studied as an alternative disinfectant for water and wastewater applications in recent years (Jiang et al, 2007, 2005, Lee et al, 2003 White and Franklin, 1998, Schink and Waite, 1980, Waite, 1979). The increasing attractiveness of ferrate (VI) to serve as a disinfectant is due to its strong oxidizing properties and its decomposition to ferric (III) ion with no known detectable disinfection by-products (DBPs). DBPs are of concern because they are suspected carcinogens. In this paper, the disinfection effectiveness of two different ferrate (VI) wet oxidation synthesis formulas in wastewater and Econlockhatchee (Econ) River water is evaluated. Ferrate (VI) is synthesized by addition of ferric chloride to a mixture of sodium hydroxide and calcium hypochlorite (refer to U.S. Patent 6,790,429 for further information). One ferrate (VI) synthesis formula uses below the stoichiometric requirement of hypochlorite and this solution will be referred to as "Low Chlorine Formula" (LCF). A second ferrate (VI) synthesis formula uses above stoichiometric requirement of hypochlorite and will be referred to as "Standard Chlorine Formula" (SCF). For applications requiring low chlorine residual effluent quality, the LCF intuitively is a more suitable disinfectant than the SCF. For applications where chlorine residual is of little or no significance, the SCF is logically a more suitable disinfectant due to lower production cost and production of higher ferrate (VI) concentrations than the LCF. The total chlorine concentration, unfiltered and filtered ferrate (VI) concentration, and dissolved organic carbon concentration pre-ferrate (VI) and post-ferrate (VI) addition of both ferrate (VI) formulas in wastewater and Econ River water was measured at a contact time of 30 minutes, as well as the measurement of total oxidants present after the addition of ferrate (VI). Disinfection capabilities were measured by comparing the quantity of Heterotrophic bacteria, Total Coliform, *Escherichia* *coli*, and Enterococcus bacteria pre- and post-ferrate (VI) at dosages of 2, 4, and 7.5 mg/L as ferrate (VI) using both ferrate formulas. The disappearance of ferrate (VI) and chlorine will be monitored for a 30-minute period after dosing LCF and SCF solutions into filtered and unfiltered wastewater samples with or without the addition of hypochloric acid.

The purpose of this research is to discover an optimum dose for inactivation of bacteria in Econ River water and wastewater for both ferrate (VI) synthesis formulas. Furthermore, this research aims to assess the chlorine residual and DOC concentration after ferrate (VI) addition for the SCF and LCF. Overall the goal of this study is to evaluate the potential of each formula to be used for water and wastewater treatment.

CHAPTER 2: LITERATURE REVIEW

2.1 Wastewater Microbial Contamination

Wastewater is a combination of liquid or water-carried wastes removed from residences, institutions, and commercial and industrial establishments, together with such groundwater, surface water, and stormwater as may be present. Wastewater contains pathogenic microorganisms, nutrients, toxic compounds and compounds that may be mutagenic or carcinogenic (Metcalf & Eddy, 2003). Microorganisms that are found in wastewater and wastewater-treatment processes are bacteria, archea, fungi, protozoa, rotifers, algae, and viruses. The following are some of the concentrations of bacterial microorganisms found in untreated wastewater: 10^7 to 10^9 MPN/100 mL of Total Coliform, 10^6 to 10^8 MPN/100 mL of *Escherichia coli (E.coli),* and 10^4 to 10^5 MPN/100 mL of Enterococci (Metcalf & Eddy, 2003).

Total coliform are an extensive class of bacteria that live in the digestive tracts of humans and animals. Many types of coliform are not harmful but some can cause health problems such as gastroenteritis. Their presence is monitored by the Florida Department of Environmental Protection (FDEP) because it indicates that there may be disease- causing agents in water contaminated with wastewater (FDEP, 2007).

E. coli is a type of fecal coliform that is frequently seen in the intestines of animals and humans; therefore, its presence in water is an indication of wastewater or animal waste contamination. It is a gram-negative, rod-shaped bacterium measuring 0.5 to 0.25-µm (Standard Methods, 1998). The majority of E. coli strains are nontoxic, however, these strains produce a powerful toxin that can cause severe illness and as a result is an emerging cause of foodborne and waterborne illness (EPA, 2006b). This bacterium is also used to indicate whether other potentially harmful bacteria may be present.

Enterococci bacteria are commonly found in feces of humans and warm-blooded animals. Presence of this bacterium in water suggests fecal pollution and a possible presence of enteric pathogens (EPA, 2006a).

2.2 River Water Microbial Contamination

Coliform bacteria are also a major microbial contaminant in river water that is used as surrogates for organisms that affect human health. Fecal coliform bacteria indicate fecal contamination in river water. The sources of contamination include but are not limited to domestic wastewater discharges, urban runoff, animal farms and grazing areas, water fowl droppings, and land application of industrial wastes (Letterman, 1999). Seven years of monthly sampling of Little Econlockhatchee River water found a fecal coliform average of 140 MPN/100mL (SJRWMD, 2007).

Measurement of the presence of Enterococcus is recommended as an indicator of ambient fresh and marine recreational water quality since there is a direct correlation between the concentration of Enterococcus and risk of gastrointestinal illness from swimming in water bodies like rivers, springs, and lakes (EPA, 2006a).

2.3 Disinfection

Disinfection is the process of destroying pathogenic microorganisms by physical or chemical means. In drinking water, primary standards are becoming increasingly strict; therefore the commonly used disinfectants (for example, chlorine and ozone) that form disinfection by-products (DBPs) may no longer be the most desirable disinfectants since DBPs are potential carcinogens. Studies have demonstrated that ferrate (VI) can achieve disinfectant goals at a very low dose (6 mg/L ferrate (VI)) and over a wide pH range (pH 5.5, 7.5, and 8) and compare favorably with chlorination (Jiang et al, 2007, 2006). In wastewater treatment, ferrate (VI) can remove 50% more color and 30% more COD and inactivate three orders of magnitude more bacteria in comparison with aluminum sulfate and ferric sulfate at equivalent or lower doses (Jiang et al 2005, 2006).

Two very significant factors in disinfection are time of contact (t) and concentration of the disinfecting agent (C) (Sawyer et al, 2003). When other factors are constant, the disinfection process can be represented as:

$$\frac{N}{N_o} \; \alpha \; C^n \; x \; t \qquad (n>0) \qquad (2.3.1)$$

To compare disinfection results for different experimental conditions such as varying reactions time, pH, temperature, and disinfectant concentrations, the following Chick-Watson kinetic model can be used:

$$\log\left(\frac{N}{N_0}\right) = -kCT \qquad (2.3.2)$$

where N_0 is the initial number of organisms, N is the remaining number of organisms at time T (min), C is the concentration of the disinfectant (mg/L), and k is the inactivation rate constant (L-mg^{-1}min^{-1}) (Cho et al, 2006).

2.3.1 Wastewater Disinfection

Secondary treatment is the minimum level required for municipal wastewater treatment plants by the U.S. EPA. The Secondary Treatment Information Regulation in the Code of Federal Regulations (e-CFR, 2008) included fecal coliform in the definition of secondary treatment and later delegated the disinfection criteria for wastewater to individual states (EPA, 1986). State fecal coliform standards range from less than or equal to 2.2 to 5000 MPN/100 mL and total coliform standards range from less than or equal to 2.2 to 10,000 MPN/100 mL (Metcalf and Eddy, 2003). Monitoring of fecal coliform is provided in secondary treatment in many wastewater treatment plants across the United States.

2.3.2 River Water Disinfection

River water quality classifications in Florida are defined by the FDEP. Regarding bacteriological quality (fecal coliform bacteria), Class III freshwater and marine water must not exceed a monthly geometric mean of 200 MPN/100 mL, 400 MPN/100 mL in more than 10% of the samples, or 800 MPN/mL on any one day; the geometric mean is based on five samples taken over a 30-day period as per 62-302-530 in the Florida Administrative Code (F.A.C) (FDEP, 2008). In addition, surface water sources such as river water usually exhibit a high potential to form disinfection by-products due to a high organic concentration (Cooper et al, 2000). This is understood because disinfection by-products form when organic materials react with chemical treatment agents such as chlorine. The maximum contaminant level (MCL) for total coliform in drinking water is no more than five percent positive samples if 40 or more samples are collected each month and no more than one positive sample if less than 40 samples are collected per month and the maximum contaminant level goal is 0 ppm (e-CFR, 2008).

2.3.3 Disinfectants

Chlorine (Cl_2), hypochlorination (OCl^-), chloramination (NH_2Cl, $NHCl_2$, and NCl_3), chlorine dioxide (ClO_2), ultraviolet light (UV), ozone (O_3), and bromine chloride (BrCl) are chemical disinfectants commonly used in water and wastewater treatment. Spellman provided an excellent review of disinfectants which is summarized below (1999). Elemental chlorine (Cl_2) has been used effectively for over 100 years. The advantages of chlorine disinfection are its dependability, cost, and effective performance. It is considered dependable because the equipment has been used for years which, consequently breakdown occurrences are rare and nominal time is needed to correct breakdowns when they do occur. The cost is relatively inexpensive in comparison to other disinfection processes and supplies are readily accessible from nearby suppliers. On the other hand, chlorine produces chloramines as well as other substances that are toxic to fish and aquatic organisms even at very low concentrations. Consequently, many State Water Control Boards established chlorine water quality standards of total residual chlorine less than or equal to 0.011 mg/L in fresh water and less than or equal to 0.0075 mg/L for chlorine-produced oxidants in saline water. Furthermore, it produces by-products that are harmful to humans that require additional treatment steps before water use. Because chlorine is a toxic material, additional safety precaution, personal protective equipment, emergency response plans, considerable training time, and additional regulatory monitoring and reporting are mandatory.

Sodium hypochlorite is frequently used to disinfect wastewater effluent. It is more expensive than chlorine but it avoids expenses related to safety. Chloramination is a chemical treatment process that combines chlorine and a small quantity of ammonia and has effectively been used to disinfect drinking water supplies. The three types of chloramines are monochloroamine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3). Recently chloramines have been preferred over free chlorine to reduce the amount of regulated DBPs in order to meet stricter drinking water standards. Chloramines react more slowly than chlorine and maintain residual for longer periods of time in water.

Chlorine dioxide is a gas that is generated from reactions including either sodium chlorate ($NaClO_3$) or sodium chlorite ($NaClO_2$). Sodium chlorite is quite expensive in comparison per unit weight of chlorine. Chlorine dioxide has advantages in a longer period of effectiveness than chlorine, lack of reaction with ammonia to form potentially toxic chloramines, inactivate bacteria at equal to or greater than chlorine in disinfection power, and a higher oxidation potential. Furthermore, chlorine dioxide requires lower levels to achieve equal effectiveness of inactivation of microbes in comparison to chlorine and it has been found to be effective against pathogens that are resistant to chlorine. Disadvantages of chlorine dioxide are that it must be generated and used on-site since it is sensitive to pressure and temperature and it is unstable and an explosive gas.

Ultraviolet disinfection is an environmentally safe and physical process that successfully destroys bacteria and viruses and produces no side effects. Advantages of UV treatment includes: it is user- and maintenance- friendly, it achieves required disinfection level in a few seconds (unlike chlorine that requires 15-30 minutes), it does not create an increase in total dissolved solids (TDS) like chlorination and dechlorination, it is easy to control, and it has a predictable outcome. The disadvantages are that the UV lamps will need to be replaced periodically, a secondary disinfectant must be used to prevent regrowth of microorganisms, and it is affected by turbidity problems, therefore its use is usually limited to secondary-treated wastewaters.

Ozone is a strong oxidizing gas that reacts with various organic molecules and is a very effective disinfectant for high-quality effluents. The advantages of ozone over chlorine are that it increases dissolved oxygen in the effluent, has a shorter contact time, has no undesirable effects on marine organisms, and decreases color and turbidity. Disadvantages of ozonation systems are that there are some safety problems associated with transportation and storage of ozone and it is considered impractical to produce ozone off-site since it decays spontaneously to oxygen. Ozone is an extremely toxic substance and can potentially create an explosive atmosphere; therefore concentration in air should not exceed 0.1 ppm. Ozone is relatively expensive in comparison to chlorine and is usually used with another disinfectant to meet disinfectant residual requirements.

Bromine chloride is a strong, oxidizing agent that has a sharp, harsh, penetrating odor. Advantages of bromine chloride is that it requires lower dosages than chlorine to achieve the same pathogen kill, is more effective and less toxic than chlorine, has less adverse environmental impacts than chlorine, and requires a shorter contact time, therefore requires smaller contact chambers. Disadvantages of bromine chloride are it is a hazardous, corrosive chemical that requires special transportation, handling, and storage, and can cause severe burns when in contact with skin and other tissues.

2.3.4 Disinfection By-Products

The regulated DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs). DBPs are of increasing concern since they are suspected carcinogens and some are known to cause chromosomal aberrations and sperm abnormalities (Metcalf & Eddy, 2003). In 1979, a maximum contaminant level (MCL) was established for total THMs (TTHMs) in drinking water at 100 μg/L based on an annual average of four quarterly samples (Minear and Amy, 1996). The MCL for DBPs for drinking water are currently 0.08 mg/L for TTHMs, 0.06 mg/L for HAAs, 0.01 mg/L for bromate, and 1.0 mg/L for chlorite (EPA, 2008). There are two common practices to reduce the concentration of DBPs; (1) natural and/or organic compounds have been removed before disinfection process occurs or (2) DBPs have been removed after the disinfection process, but these cause a significant overall increase in cost of water treatment (Jiang, 2007). The by-products associated with chlorine are THMs, HAAs, haloacetonitriles, halopicin, cyanogens chlorite and bromide, chloral hydrate, and MX/EMX. Other oxidants used in disinfection produce by-products as well (Minear and Amy, 1996). By-products associated with chloramines are THMs, HAAs, nitrate and nitrite, cyanogens chloride and bromide, and 1,1-dichloropropanone. By-products formed from chlorine dioxide are chlorite and chlorate. Ozone DBPs are bromate, BDOC, aldehydes, ketonacids, bromoform, peroxides, and epoxides. These are the known by-products but there may be more formed that have yet to be detected. Currently there are no known by-products formed with UV disinfection. After THMs are formed they are commonly removed by air stripping or granular activated carbon (GAC). However, due to the discovery of HAAs, which are nonvolatile, the option to utilize air stripping has becomes less attractive. The alternative option (GAC) does not have a high capacity for THM removal.

2.4 Ferrate

Ferrate (VI) is a +6 oxidation state of iron that demonstrates useful properties such as oxidizing power and selective reactivity, and decomposes to the more common ion state, ferric (III). Under acidic conditions, ferrate (VI) has the strongest reduction potential when compared to hypochlorite, ozone, hydrogen peroxide, and permanganate (Lee et al, 2004). The reduction potential of ferrate (VI) at an acidic pH is 2.20 V and 0.70 V at a basic pH which suggests that the oxidation power is highly dependent on pH. Studies suggest that ferrate (VI) selectively oxidizes organic compounds such as alcohols, amines, sulfur derivatives, and amino acids (Sharma, 2002).

To date, there are three general methodologies used to synthesize ferrate (VI); electrolysis, dry oxidation, and wet oxidation (Lee et al, 2004). Electrolysis uses a pure iron metal electrode anodized in concentrated alkaline solution. The following half-cell reactions occur at an anode:

$$Fe + 8OH^- \rightarrow FeO_4^{2-} + 4H_2O + 6e^- \qquad (2.4.1)$$

and the following half-cell reaction at the cathode:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \qquad (2.4.2)$$

Dry oxidation requires high temperature and pressure when reacting iron oxides with oxidants. To synthesize ferrate (VI) by dry oxidation the following reaction occurs:

$$Fe_2O_3 + 3Na_2O_2 \rightarrow 2Na_2FeO_4 + Na_2O \qquad (2.4.3)$$

The wet oxidation procedure for ferrate synthesis uses concentrated hypochlorite in a strong basic solution such as sodium hydroxide (NaOH) to oxidize ferric (III) ion. Additionally, an excess amount of potassium hydroxide is added to the soluble ferrate (VI) to precipitate potassium ferrate salt (K_2FeO_4). The following reactions summarize the wet oxidation synthesis of Fe (VI):

$$2Fe(OH)_3 + 3NaClO + 4\ NaOH \rightarrow 2Na_2FeO_4 + 3NaCl + 5H_2O \qquad (2.4.4)$$

$$2Na_2FeO_4 + 2KOH \rightarrow K_2FeO_4\downarrow + 2NaOH \qquad (2.4.5)$$

It has been reported that one major disadvantage of traditional wet oxidation procedures that include potassium is the need for pure reagents which lead to higher costs (Lee et al, 2004). Pure reagents are needed to prevent the decomposition of ferrate (VI) by impurities such as transition metals. To counter this disadvantage, Ferrate Treatment Technologies, LLC (Orlando, FL) has patented (Patent No. 6,790,429) an inexpensive onsite wet oxidation method to synthesis ferrate (VI) as shown below:

$$H_2O + 2NaOH + 3CaOCl + FeCl_3 \rightarrow Na_2FeO_4 + 3CaCl_2 + 2H_2O \qquad (2.4.6)$$

A major advantage of ferrate (VI) is the decomposition to ferric ions such as ferric hydroxide as shown below (2.4.7) (Jiang and Lloyd, 2002).

$$4Na_2FeO_4 + 10H_2O \rightarrow 4Fe(OH)_3\downarrow + 8NaOH + 3O_2\uparrow \qquad (2.4.7)$$

Ferrate (VI) has a red-violet color in aqueous solution, and in phosphate buffer at pH 9.2, has a maximum absorption at 510 nm (Lee et al, 2004). At 510 nm, an extinction coefficient has been found to be 1150 $M^{-1}cm^{-1}$ at pH 9.5 to 10.5 by Bielski and Thomas (1987) and pH 9.2 by Lee et al (2004). Experiments using Missouri River water, Colombia, Missouri tap water, and three types of deep well water suggested that ferrate is effective at flocculating suspended solids, co-precipitates certain transition metal ions, and can destroy several types of common bacteria in water (Murmann and Robinson, 1974).

Regarding drinking water treatment, studies have shown that ferrate (VI) can remove 10-20% more UV_{254}-abs and DOC than ferric sulfate for an equivalent dose over a pH range of 6 and 8 (Jiang et al, 2006). The majority of natural organic matter in surface and groundwater are humic substances which can react with chlorine to produce DBPs. Another study demonstrated that ferrate (VI) performed better than ferric sulfate at lower doses when treating water containing humic and fulvic acids as measured by UV_{254} absorbance, DOC, THMFP, and ferrate (VI) achieved lower iron residual concentrations (Jiang and Wang, 2003). In wastewater treatment, ferrate (VI) can remove 50% more color and 30% more chemical oxygen demand (COD) in comparison with commonly used coagulants, ferric sulfate and aluminum sulfate at the same or smaller doses (Jiang et al, 2005). In another study, ferrate (VI) provided substantial reduction of the following priority pollutants: trichloroethylene, naphthalene, 1,2-dichlorobenzene, and bromodichloromethane (De Luca et al, 1983). Removal of manganese and iron from potable water was also observed suggesting that ferrate (VI) may serve as a promising flocculant (White and Franklin, 1998).

CHAPTER 3: MATERIALS AND METHODS

Through measuring the chlorine residual and ferrate decomposition over time of the Low Chlorine Ferrate (VI) Formula (LCF) and Standard Chlorine Ferrate (VI) Formula (SCF) in wastewater, kinetic information of the both formulas can be evaluated. The THM formation of both ferrate (VI) formulas at 2, 4, and 7.5 mg/L ferrate (VI) in Econ River water is also measured. This information along with the dissolved organic carbon concentrations and inactivation of the following microorganisms; Total Coliform, *E. Coli*, Enterococcus, and heterotrophic bacteria at various doses in Econ River water and wastewater is measured to evaluate the potential for each formula to be used for water and wastewater treatment.

The sample wastewater was secondary wastewater prior to disinfection treatment and was collected at the Eastern Regional Water Supply Facility (ERWF) in Orlando, Florida. The sample Econlockhatchee River water was collected at Blanchard Park in Orlando, Florida. These water samples were collected in closed top, plastic containers and stored at 4°C and used within one week. Before experimentation began with Econ River water, the water was filtered through a Whatman 47-mm GF/C glass fiber filter in a suction flask. Both ferrate (VI) solutions were prepared by addition of ferric chloride ($FeCl_3$) to mixture sodium hydroxide (NaOH) and calcium hypochlorite ($Ca(OCl)_2$) (refer to U.S. Patent 6,790,429 for more information). One ferrate (VI) synthesis formula uses below the stoichiometric requirement of hypochlorite and this solution is referred to as "Low Chlorine Formula" (LCF). A second ferrate (VI) synthesis formula uses above stoichiometric requirement of hypochlorite and is referred to as "Standard Chlorine Formula" (SCF). For applications requiring low chlorine residual effluent quality, the LCF intuitively is a more suitable disinfectant than the SCF. For applications where chlorine residual is of little or no significance, the SCF is logically a more suitable disinfectant due to lower production cost and production of higher ferrate (VI) concentrations than the LCF.

3.1 Kinetic Experiments

Evaluations of the kinetics of ferrate (VI) disappearance for both formulations were conducted. The ferrate (VI) concentration, total oxidant (ferrate (VI) and chlorine), and chlorine residual of solutions treated with 7.5 mg/L of ferrate (VI) were measured. A Phipps and Bird standard programmable jar tester was used. The programmable timer was used to mix the solution for 2 minutes at 200 rpm and then for 28 minutes at 75 rpm. Every ten minutes 100-mL of solution treated with ferrate (VI) was tested to develop kinetic information. The filtered and unfiltered ferrate (VI) concentration was measured using a spectrophotometric procedure.

3.2 Disinfection Experiments

For disinfection experimentation, ferrate (VI) doses of 2, 4, and 7.5 mg/L were added to both wastewater and Econ River samples and mixed on a stirring plate with a magnetic stirrer for 30 minutes. After 30 minutes, 100 mL of sample were added to a 100-mL Coliform Test Vial containing a sodium thiosulfate pellet to quench the reaction instantaneously.

3.3 Analytical Methods

3.3.1 Ferrate Concentration

Two different wet oxidation formulations were used to synthesize ferrate (VI). Ferrate (VI) was measured using a spectrophotometric method (USB 2000 Fiber Ocean Optic Spectrometer). A measured amount of ferrate (VI) was diluted with a carbonate buffer solution and filtered. The absorbance at its characteristic wavelength (510 nm) was then measured. The absorbance of the ferrate solution was translated to the ferrate concentration using the predetermined extinction coefficient, ε, of 1150 $M^{-1}cm^{-1}$ and Beer's Law (3.3.1) where A is the absorbance, l is the pathlength (cm), and c is the concentration (M) (Rios, 2004).

$$A = \varepsilon l c \tag{3.3.1}$$

Since the untreated wastewater and Econ River water absorbed light at 510 nm that was dependent on the concentration of organic matter, it was not used as a blank sample to zero the photometer. Instead, the spectrophotometer was zeroed using distilled water and then the absorbance of unfiltered and filtered untreated sample was measured with respect to the distilled water and positive readings resulted. Therefore to calculate the ferrate (VI) concentration, the absorbance of untreated wastewater/river water was subtracted from the absorbance of each treated sample. In some instances, the calculated ferrate (VI) absorbance was negative which suggests that color was removed by ferrate (VI) addition. Negative values were treated as zero but this methodology was recognized as a problem. The data is in the Appendix and may be re-interpreted as this phenomenon is better understood.

3.3.2 Chlorine and Total Oxidant

The total oxidant content was measured after filtering the sample with a 1.5-µm Whatman 25-mm GD/X Syringe filter until there was a total of 25 mL of filtered sample. The 25-mL sample was filtered directly into a 1-inch square glass sample cell to which one Hach DPD Total Chlorine Reagent powder pillows was added. The sample was swirled for 20 seconds and then after a three-minute reaction time it was inserted into the cell holder of the DR 4000 Hach Spectrophotometer 48000 Model (HACH Co., Loveland, CO) (Hach Program 1450, 530 nm wavelength). The Hach DPD method used applies to low total chlorine samples from zero to 2 mg/L Cl_2, has an estimated detection limit of 0.01 mg/L Cl_2, and to measure total chlorine absorbance, the pH of the sample must be adjusted to pH 6-7 to avoid a pH intereference (Hach, 2003). The pH was adjusted using 1 N HCl. Since the untreated wastewater and Econ River water contained an absorbance at 530 nm it was not used as the blank sample to zero on. Instead, the Hach Spectrometer was zeroed using distilled water and then the absorbance of filtered untreated secondary wastewater with a Hach DPD Total Chlorine Reagent powder pillow was measured with respect to the distilled water. To calculate the total chlorine and total oxidant absorbances with respect to the secondary wastewater, the absorbance of wastewater with DPD pillow was subtracted from the absorbance of each sample.

The total chlorine concentration was measured using the same procedure as the total oxidant content except the pH of the sample was decreased to 6.0 to 6.35 (prior to filtration) to eliminate ferrate (VI) in the sample. That is, the DPD colorimetric method was used to measure both total oxidant (ferrate (VI) and chlorine) and total chlorine. Studies show that ferrate (VI) is relatively stable between pH 9-10 (Li et al, 2005). However, ferrate (VI) decomposes at a rapid rate at pH less than nine and studies have demonstrated a ferrate (VI) half life of approximately 20 seconds at pH 6 (Sharma, 2001).

In order to calculate the total chlorine concentration, a standard curve of absorbances of known total chlorine concentrations versus known total chlorine concentration was developed. Known Hach Gel Standards between 0.18 and 1.47 mg/L Cl_2 was used for the low range DPD chlorine method. Total oxidant absorbances instead of concentrations were reported because of complications of creating a standard curve for total oxidant. Potassium ferrate (K_2FeO_4) dissolves in 4 N NaOH but the Hach DPD Total Chlorine Reagent powder used in total oxidant measurement does not dissolve in 4 N NaOH therefore, the absorbance of a known concentration of ferrate could not be obtained to define a mathematical relationship between absorbance and total oxidant concentration.

3.3.3 Dissolved Organic Carbon

Sample was filtered through a 0.45-μm Whatman membrane filter using a suction flask and applied vacuum. The filtered sample was transferred to 40-mL muffled glass vials, covered with tin foil and capped. DOC was measured using the Phoenix 8000 TOC Analyzer (Teledyne Technologies Co., Mason, OH). To calculate the DOC concentration, a standard curve using 200 mg/L-C stock solution from 425 mg/L KHP was produced for each analytical run. Known standard concentrations of 0.5, 1, 2, 5, 10, and 20 mg/L-C were prepared from the 200 mg/L-C stock solution of KHP. To prepare a standard curve, the counts of each sample provided by the TOC Analyzer versus the known concentration are graphed. From this data, an equation can be developed to measure the concentration of each sample when supplied counts from the TOC Analyzer.

3.3.4 Microbiology

Heterotrophic Bacteria

Heterotrophic bacteria were quantified by the Heterotrophic Plate Count (HPC) method (Standard Methods, 1998). Sample volume of 0.1 or 1 mL was pipetted onto R2A agar petri dishes, depending on the microbial concentration of the sample. Only the treated Econ River water samples had colony forming unit (CFU) counts below the accepted range of 30 CFU, therefore 1 mL of Econ River water sample was used. The R2A agar was autoclaved for 15 minutes prior to pouring into 100x15-mL petri dishes. Once the R2A agar solidified in the petri dishes, dishes were inverted overnight before using immediately; otherwise they were refrigerated at 4° C and used within 2 weeks. Two closed petri dishes, two open agar petri dishes, and three open petri dishes containing dilution buffer were placed in the hood during experimentation to serve as controls. The dilution buffer used for dilutions during experimentation was prepared by diluting 1.25-mL of stock phosphate buffer and 5-mL of magnesium chloride hydrate to 1 L with distilled water and then autoclaving for 15 minutes. The stock phosphate buffer was prepared by adding 17.0 g KH_2PO_4 to 250- mL of distilled water. The pH of the phosphate buffer was adjusted to 7.2 +/- 0.05 using 1 N NaOH. The solution was then transferred to a 500-mL volumetric flask and diluted to 500-mL using distilled water. The magnesium chloride hydrate was prepared by adding 8.11 g $MgCl_2 \bullet 6H_2O$ and to 100-mL of distilled water. The petri dishes were inverted and incubated for three days at 26°C. The colonies were counted manually using a Quebec Colony Counter (Reichert, Inc., Depew, NY) and expressed as CFUs/mL.

Total Coliform and E. coli

Colilert substrate was added to a 100-mL sample at the appropriate dilution and transferred into the IDEXX Quanti-Tray (IDEXX Laboratories, Inc., Westbrook, ME). The Quanti-Tray 2000 containing the sample was sealed with an IDEXX Quanti-Tray Sealer and incubated at 35°C for 24 hours. After the 24-hour incubation, the total coliform was quantified by totaling the number of wells with yellow color. *Klebsiella pneumoniae* was used as a positive control and *Pseudimonas aeruginosa* as a negative control. For *E. coli* enumeration, Colilert substrate was added to a 100-mL sample at the appropriate dilution and transferred into the IDEXX Quanti-Tray. The Quanti-Tray 2000 containing sample was sealed with an IDEXX

Quanti-Tray Sealer and incubated at 35°C for 24 hours. After the 24-hour incubation, the *E. coli* is quantified by totaling wells fluorescing under ultraviolet light. *E. coli* was used as a positive control.

Enterococcus Bacteria

Enterolert™ substrate was added to a 100-mL sample at the appropriate dilution and transferred into the IDEXX Quanti-Tray. The Quanti-Tray 2000 containing the sample was sealed with an IDEXX Quanti-Tray Sealer and incubated at 41°C for 24 hours. After the 24-hour incubation, the Enterococcus was quantified by the well showing blue fluorescence under ultraviolet light. *Enterococcus faecium* and *Enterococcus faecalis* combined was used as positive control. All controls used in the IDEXX Quanti-Tray experimentation were diluted 1:1000 using dilution buffer except for the *Pseudimonas aeruginosa* which was diluted to 1:100 and transferred into the IDEXX Quanti-Tray. The Quanti-Tray 2000 containing the control cultures was sealed with an IDEXX Quanti-Tray Sealer and incubated at the appropriate temperature for 24 hours. The *Enterococcus faecium* (American Type Culture Collection (ATCC) Order #193434) (ATCC, Manassas, VA) and *Enterococcus faecalis* (ATCC Order #19433) cultures were combined to serve as a positive control for the Enterococcus bacteria group. These cultures and *E. coli* (ATCC Order #11303), *Klebsiella pneumoniae* (ATCC Order #13882) and *Pseudimonas aeruginosa* (ATCC Order #10145) were prepared according to the instructions provided by the manufacturer. They were added to 100-mL of 8 g/L Difco Nutrient broth (Becton Dickinson & Co., Franklin Lakes, NJ). . Under sterile conditions at room temperature of 22ºC, they were shaken at 25 rpm for 3 to 4 days and kept refrigerated at 4 °C for up to one month.

3.3.5 Trihalomethanes

Ferrate (VI) treated river water samples were poured in muffled glass bottles. After a 30-minute contact time, 1 mL of sodium thiosulfate solution added to ferrate treated samples; glass bottles were then capped tightly to prevent air bubbles forming, and refrigerated at 4°C. Samples were removed from the walk-in cooler and allowed to cool to room temperature before extraction. Once at room temperature, a 10-mL aliquot of sample was transferred to a clean, muffled 15-mL vial using a volumetric pipette. HPLC-grade hexane (2 mL) was added to the aliquot using a 2-mL pipette. Vials were manually shaken for two minutes, with the aid of a stopwatch, and allowed to settle for two minutes after shaking. A small sample (2 μL) of the top (organic) layer was injected into the gas chromatograph (HP5890 with Electron-Capture Detection (ECD)). Resulting chromatograms were analyzed by comparison to primary standard material purchased externally.

Standards of 0, 10, 20, and 40 ppb where used to generate standard curves. The curves were shown to be linear with R-values ranging from 0.9880 to 0.9997. In addition, two separately prepared standard check solutions were prepared at 20 and 40 ppb in each THM (i.e. 80 ppb and 160 ppb total THM respectively). Recoveries were 80 ppb total and 163 ppb total respectively (or 100% and 102%).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The effectiveness of two different wet oxidation ferrate (VI) synthesis formulations to disinfect wastewater and river water was studied. More specifically, the capability of the two ferrate (VI) formulas to inactivate Total Coliform, *Escherichia coli* (*E. coli*), Enterococcus, and heterotrophic bacteria at a 30-minute contact time was investigated. The Standard Chlorine Ferrate (VI) formulation (SCF) requires more hypochlorite addition than the Low Chlorine Ferrate (VI) formulation (LCF). Other parameters included the chlorine residual, ferrate (VI) concentration, total oxidant (ferrate (VI) and chlorine) and dissolved organic carbon at a 30-minute contact time. Ferrate (VI) doses of 2, 4, and 7.5 mg/L were used to treat secondary effluent prior to disinfection from the Eastern Regional Water Supply Facility and Econlockhatchee River water in Orlando, Florida.

4.2 Low Chlorine Formula Ferrate (VI) and Chlorine Disappearance Kinetics

As shown in Figure 1, the LCF ferrate (VI) decomposed within 30 minutes at a pH of 10. There was also a noticeable instantaneous demand of ferrate (VI). Immediately after 7.5 mg/L of ferrate (VI) was added, the maximum ferrate (VI) concentration at time zero was 1.25 to 4.25 mg/L for a ferrate (VI) demand of 6.25 to 3.25 mg/L. After a contact time of 30 minutes the maximum ferrate (VI) concentration for three runs was approximately 1.25 mg/L and ranged from zero to 1.25 mg/L ferrate (VI). The ferrate (VI) concentration variation between runs may be attributed to the presence of varying concentrations of reducing agents in the treated wastewater samples.

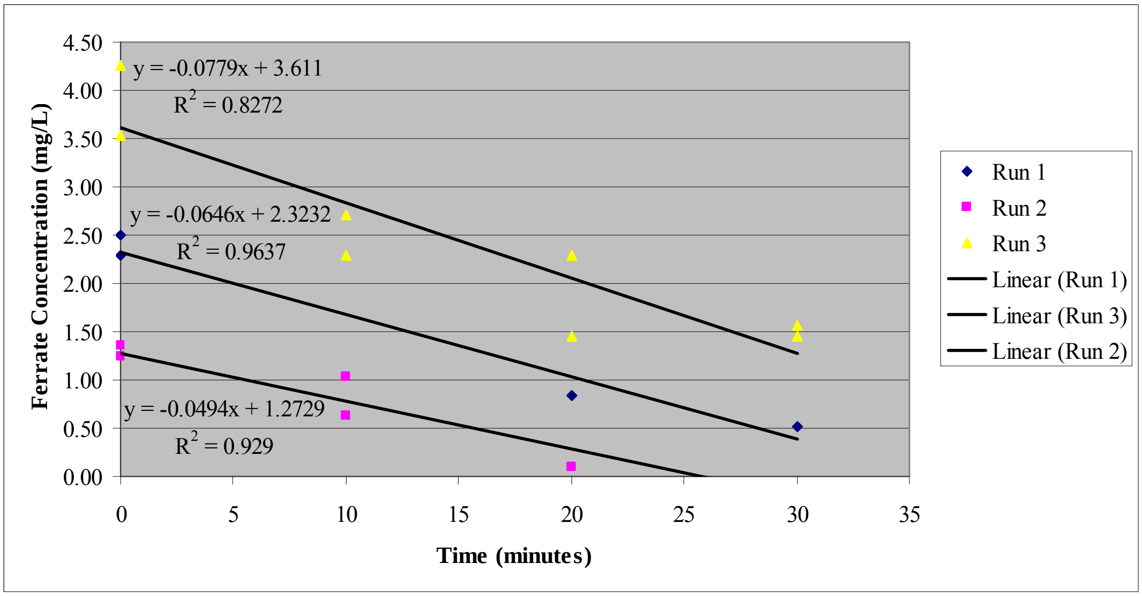


Figure 1: Filtered Ferrate Concentration vs. Time of 7.5 mg/L Low Chlorine Ferrate (VI) Synthesis in secondary wastewater (pH=10)

The rate of ferrate (VI) disappearance among the separate runs declines with the initial ferrate (VI) concentration; thus the rate of ferrate (VI) disappearance is dependent of initial ferrate (VI) concentration suggesting that this maybe a first order reaction. A first order reaction is defined in equation 4.2.1 where C is the concentration, t is the time, and k is the rate constant (Metcalf & Eddy, 2003).

$$\frac{dC}{dt} = kC \qquad (4.2.1)$$

Through graphical analysis of first order (Figure 2) compared to zero order reaction order (Appendix A: Figure 15) the reaction order was determined to be first order with the correlation coefficient (R^2) equaling 0.9947 and the rate constant (k) equaling -0.05 min^{-1}.

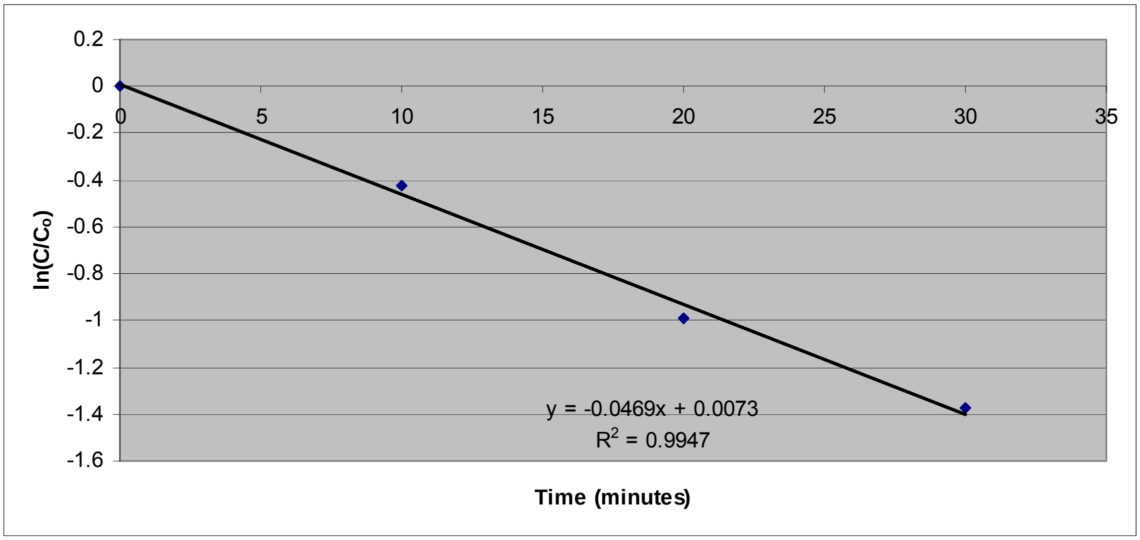


Figure 2: First Order Analysis of Averaged Ferrate (VI) concentration in wastewater vs. Time for Low Chlorine Formula

The total oxidant (ferrate (VI) and chlorine) and total chlorine residual in LCF ferrate (VI) added to wastewater over 30 minutes was measured using the DPD method without pH adjustment and spectrophotometry at 530 nm (Figures 3 - 5). To make a visual comparison between the chlorine and total oxidant present in the treated sample, both total oxidant and chlorine absorbances were plotted in Figures 3 through 5 together. Figures 3 to 5 show that ferrate (VI) is the majority of total oxidant and is decomposing, whereas Cl_2 is constant. The chlorine residual concentration of LCF ferrate (VI) in wastewater dosed with 7.5 mg/L varied from 0.2 to 0.6 mg/L Cl_2 (Appendix C-2).

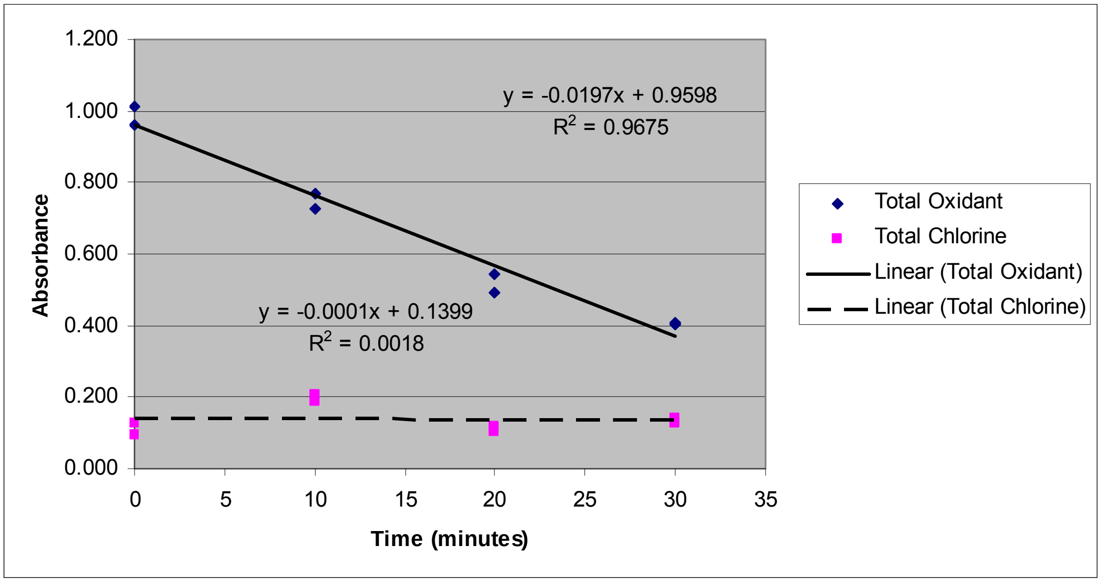


Figure 3:Run 1-Total Oxidant and Total Chlorine Absorbance Vs Time Low Chlorine Ferrate (VI) Synthesis in secondary wastewater at 530 nm (7.5 mg/L ferrate (VI), pH=10)

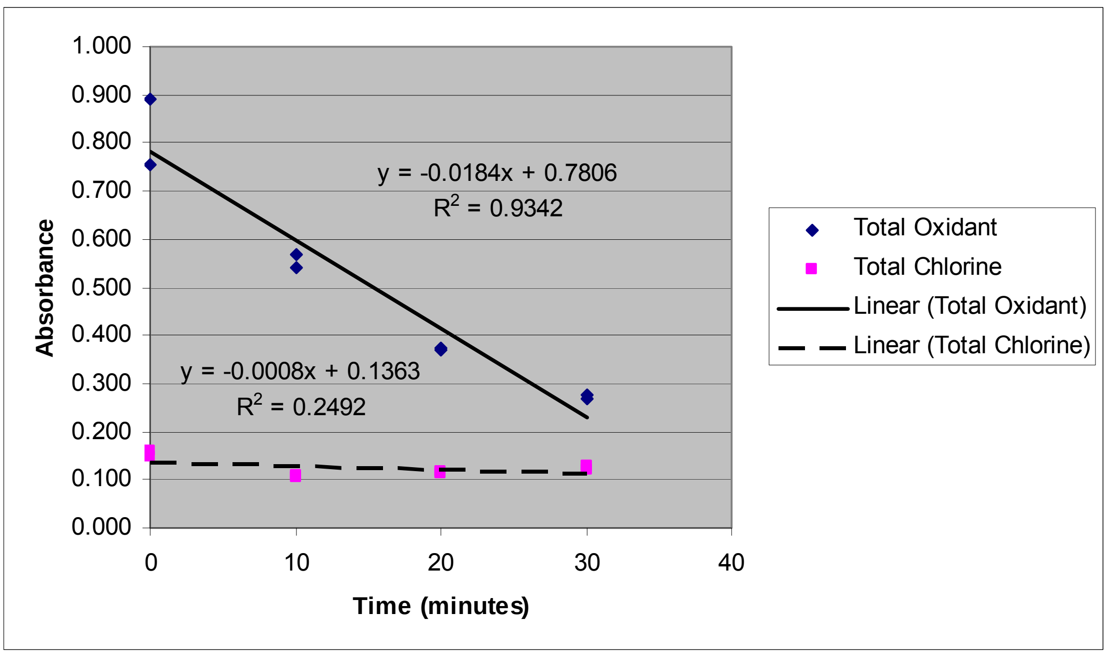


Figure 4: Run 2- Total Oxidant and Total Chlorine Absorbance Vs Time Low Chlorine Ferrate (VI) Synthesis in secondary wastewater at 530 nm (7.5 mg/L ferrate (VI), pH=10)

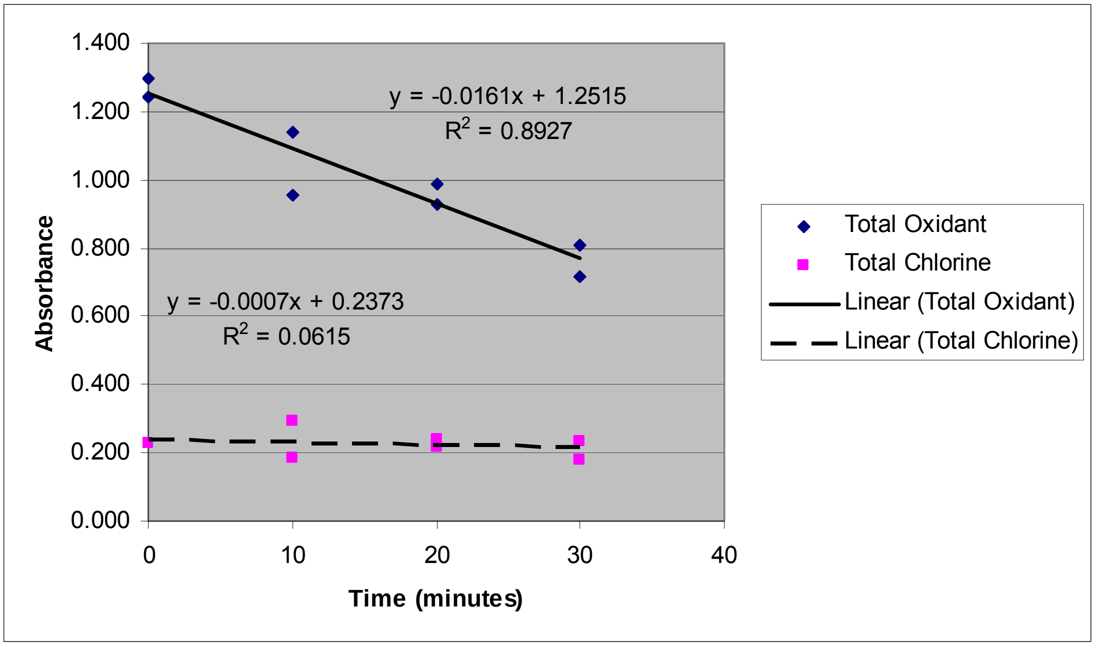


Figure 5: Run 3- Total Oxidant and Total Chlorine Absorbance Vs Time Low Chlorine Ferrate (VI) Synthesis in secondary wastewater at 530 nm (7.5 mg/L ferrate (VI), pH=10)

Another experiment was conducted in which the filtered ferrate (VI) concentration and total chlorine concentration was measured over a 30-minute period after the pH of wastewater dosed with 7.5 mg/L ferrate (VI) was adjusted to 6-6.35. The measured values of ferrate (VI) concentration were below the detection limit. These data support the fact that at pH 6.0, no ferrate was present. Figure 6 shows the total chlorine concentrations ranging from 0.18 to 0.20 mg/L Cl_2 at a 30-minute contact time.

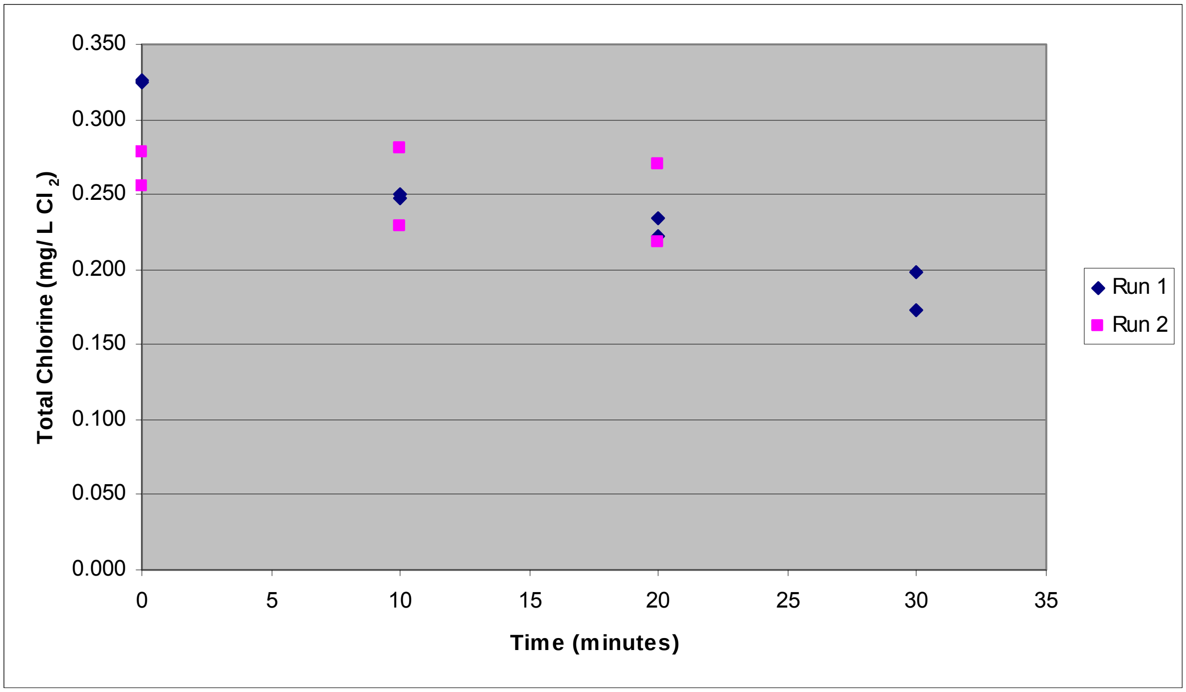


Figure 6: Total Chlorine Concentration Vs Time of 7.5 mg/L Low Chlorine Ferrate (VI) Synthesis in secondary wastewater at 530 nm (pH 6.0)

4.3 Standard Formula Ferrate (VI) and Chlorine Disappearance Kinetics

As shown in Figure 7, the SCF ferrate (VI) decomposed over a 30-minute period at a pH of 9.6. As with LCF ferrate (VI), there is a noticeable instantaneous demand of ferrate (VI). Immediately after 7.5 mg/L of ferrate (VI) were added, the maximum ferrate (VI) concentration at time zero was 5.0 and 4.2 mg/L, for a ferrate (VI) demand of 2.5 and 3.3 mg/L ferrate (VI). This was much lower than the demand of the LCF. After a contact time of 30 minutes, the maximum ferrate (VI) concentration for two runs at time zero was 3.25 mg/L and the ferrate (VI) concentration ranged from 2.8 to 3.25 mg/L ferrate (VI). Comparing the two formulas with regard to ferrate (VI) concentration, the data show that there is approximately double the amount of ferrate (VI) remaining at 30 minutes with the SCF than with the LCF.

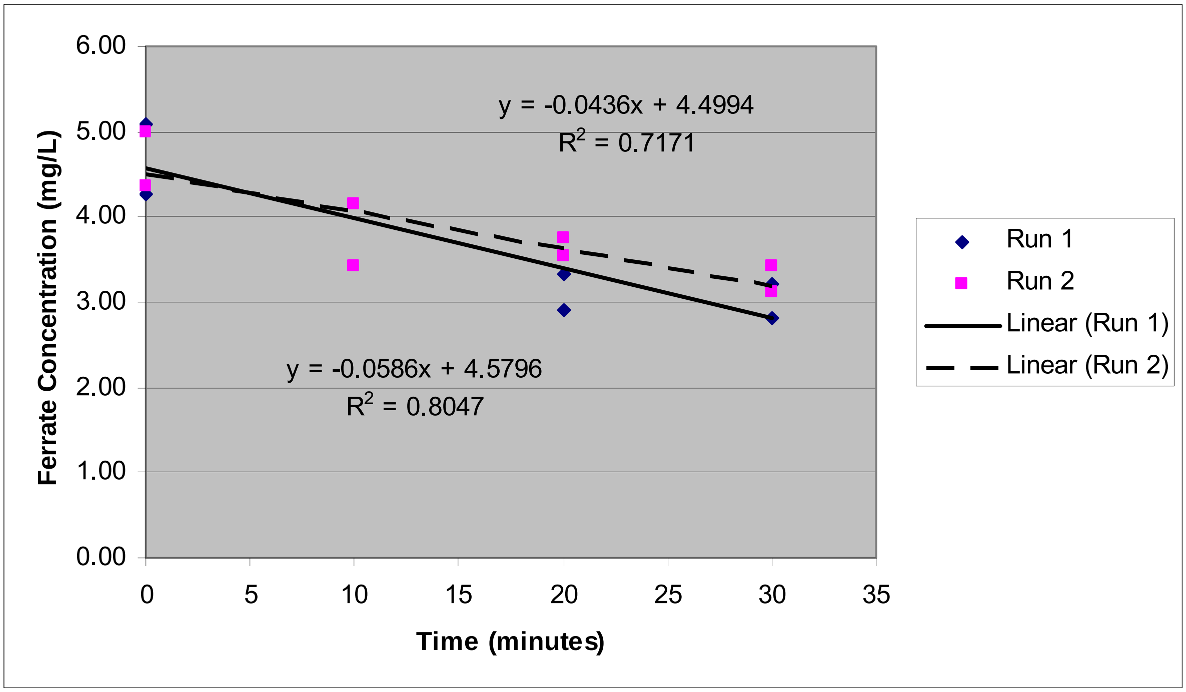


Figure 7: Filtered Ferrate Concentration vs. Time of 7.5 mg/L Standard ferrate (VI) Synthesis in secondary wastewater at 510nm (pH=9.6)

Through graphical analysis of first order (Figure 8) compared to zero order reaction (Appendix A: Figure 16) the reaction order was determined to be first order with the correlation coefficient (R^2) equaling 0.9578 and the rate constant (k) equaling -0.01 min^{-1}.

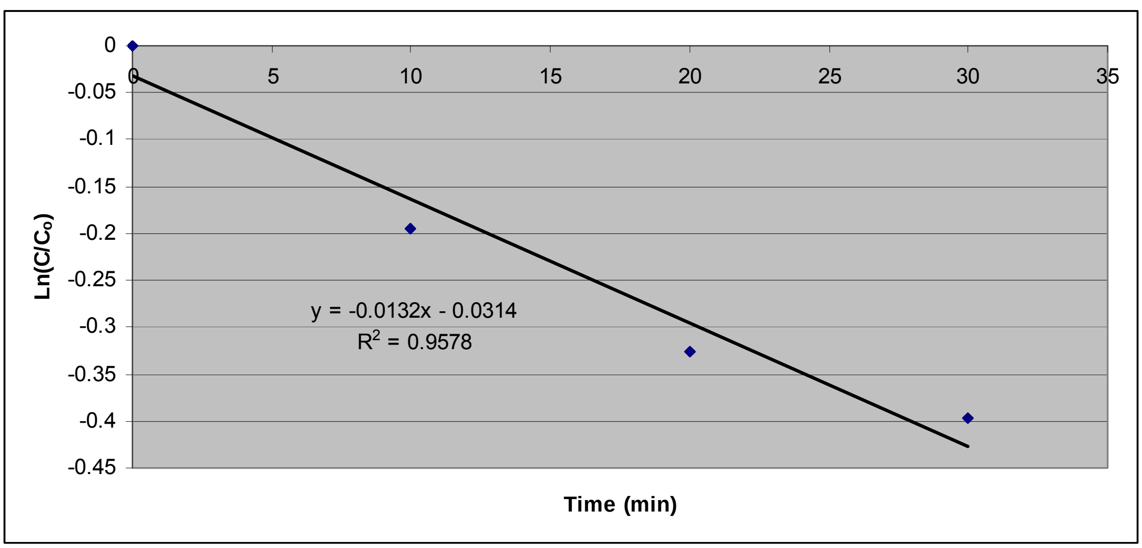


Figure 8: First Order Analysis of Averaged Ferrate (VI) concentration in secondary wastewater vs. Time for Standard Formula

The absorbance of both the total oxidant and total chlorine residual of 7.5 mg/L SCF ferrate (VI) in wastewater over 30 minutes was measured using a Hach spectrophotometer at 530 nm (Figures 9 and 10). The total oxidant and chlorine measurements are larger for the SCF in comparison to the LCF which was to be expected since the SCF requires more hypochlorite addition during synthesis. There is noticeably more scatter in this data set than the LCF data set, as suggested by the lower R^2 values.

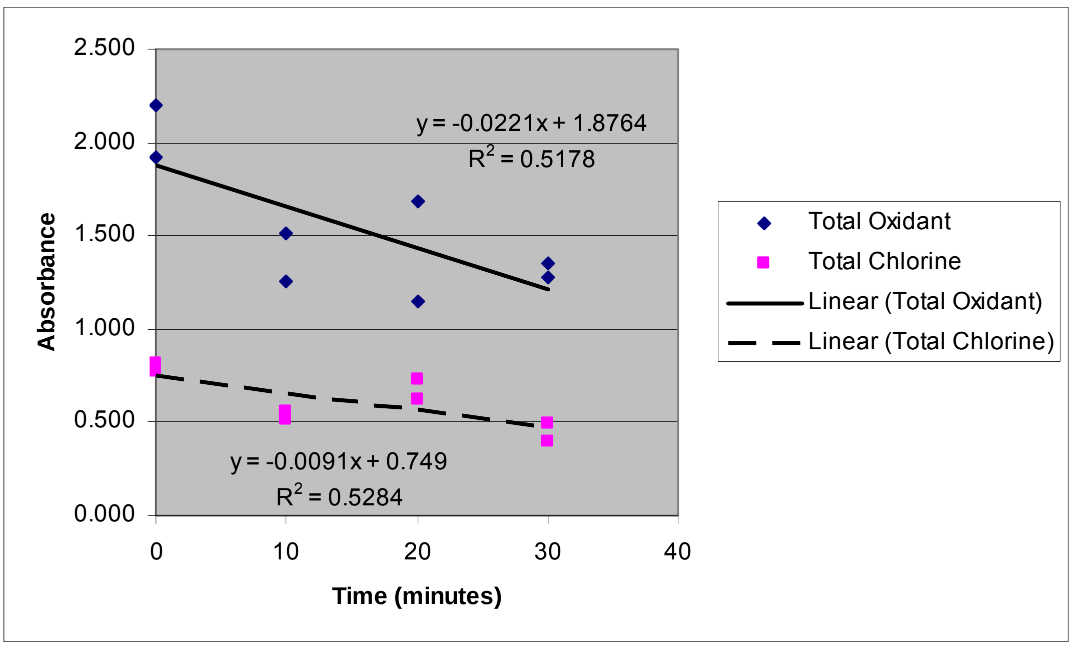


Figure 9: Run 1- Total Oxidant and Total Chlorine Absorbance vs. Time of 7.5 mg/L Standard ferrate (VI) Synthesis in secondary wastewater at 530 nm (pH=9.6)

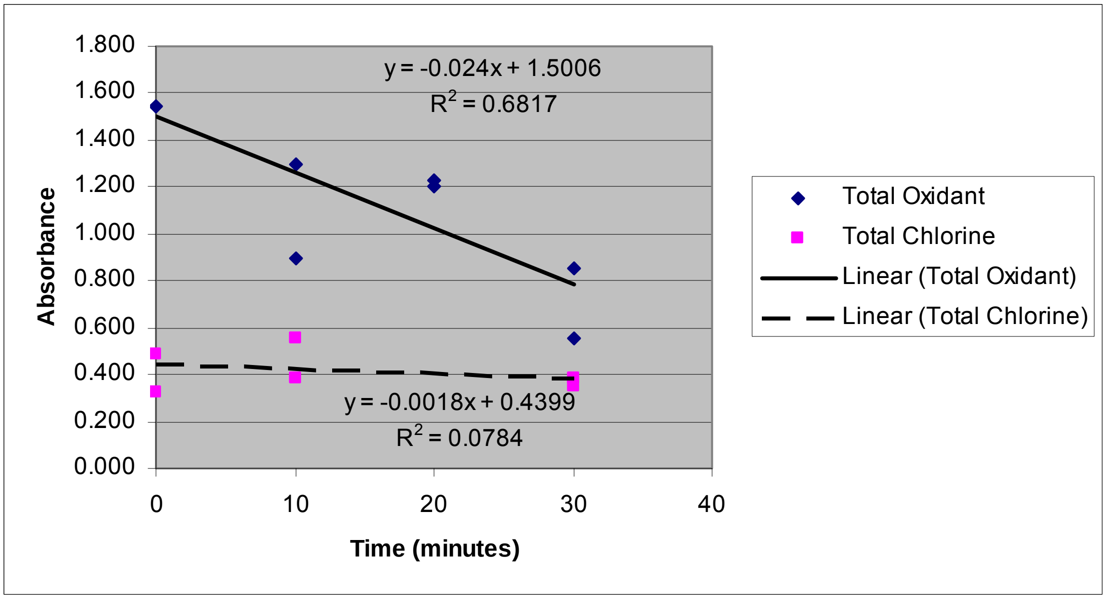


Figure 10: Run 2-Total Oxidant and Total Chlorine Absorbance Vs Time of 7.5 mg/L Standard Chlorine ferrate (VI) Synthesis in secondary wastewater at 530 nm (unadjusted pH=9.6)

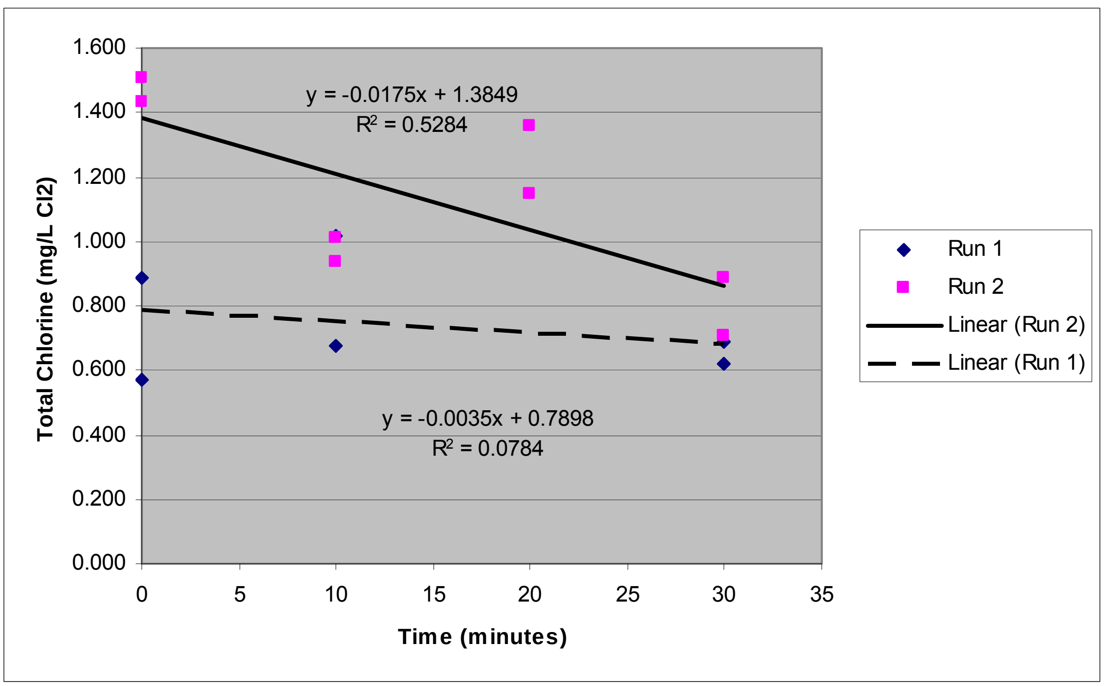


Figure 11: Total Chlorine Concentration Vs Time of 7.5 mg/L Standard ferrate (VI) Synthesis in secondary wastewater at 530 nm (pH=6-6.35)

The chlorine residual concentration for SCF ferrate (VI) in wastewater dosed with 7.5 mg/L ferrate (VI) and pH adjustment to 6-6.35 was 1.4 and 0.8 mg/L Cl_2 for two separate runs

(Figure 11) which is significantly larger than the chlorine residual concentration for LCF ferrate (VI).

Ferrate (VI) concentration as a function of time was measured for the SCF ferrate (VI) dosed at 7.5 mg/L while holding a pH at 6.0 as well. At this pH the values were below the detection limit. The total chlorine concentration at pH 6.0 varied over the 30-minute period from a maximum of approximately 0.8 mg/L Cl_2 to 0.6 mg/L Cl_2 (Figure 12). The total chlorine concentrations are noticeable higher in Figure 9 than in Figure 10. In Figure 11, the pH is adjusted to 6-6.35 every 10-minutes allowing ferrate (VI) to decompose instantaneously and chlorine to be measured whereas in Figure 12, the pH is adjusted at time zero allowing only chlorine to disappear over the 30-minute contact time.

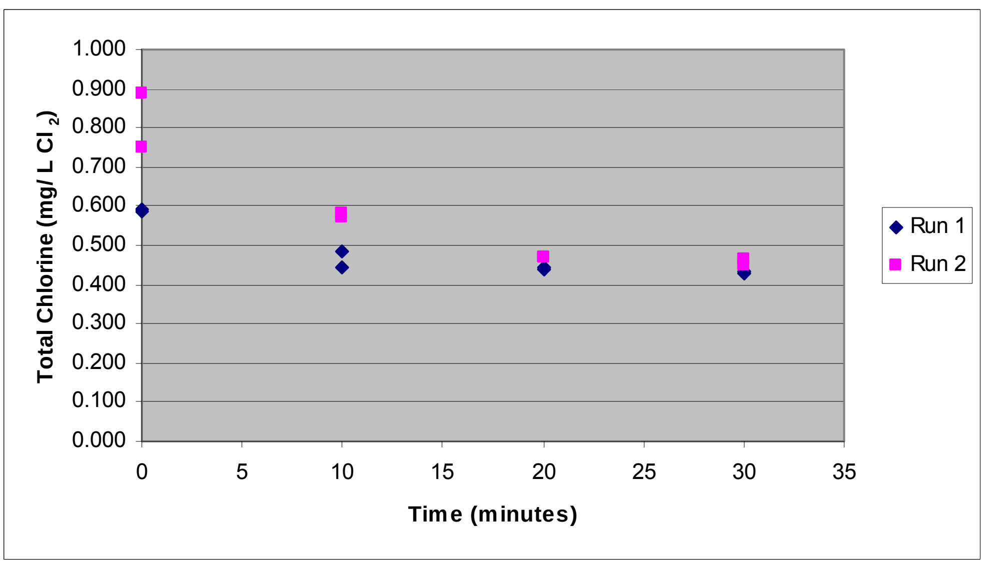


Figure 12: Total Chlorine Concentration Vs Time of 7.5 mg/L Standard Fe (VI) Synthesis in secondary wastewater at 530 nm (pH 6.0)

The total chlorine (Appendix A, Figures 17 and 18) for both ferrate (VI) formulas at 2, 4 and 7.5 mg/L in Econ River water and wastewater at a 30-minute contact time show that both increase with an increase in dosage. The total chlorine concentration of LCF ferrate (VI) formula in Econ River water is not shown since it was zero at all doses.

4.4 Effect of Ferrate (VI) Addition on DOC

The DOC concentration of wastewater and Econ River water treated using both formulas was measured after a 30-minute contact time at doses of 2, 4, and 7.5 mg/L of ferrate (VI) (Figures 13 and 14). The initial DOC in river water was greater than wastewater. The initial DOC in Econ River water for the LCF and SCF was 13.2 mg/L C and 14.8 mg/L C, respectively and in wastewater it was 11.3 mg/L C and 11.9 mg/L C, respectively. SCF and LCF initial DOC concentrations are different, even though the same raw water was used for both experiments. The LCF was synthesized and used for treatment one day and the SCF was synthesized and used for treatment the following day. The lapse of time between experimentation may account for this observation. With both formulas, the DOC concentration decreased; i.e. there was greater DOC destruction as the ferrate (VI) dose increased. The SCF achieved 4.6 % DOC removal and the LCF achieved 5.6 % DOC removal in secondary wastewater dosed with 7.5 mg/L ferrate (VI). Both ferrate (VI) formulas achieved approximately 22% DOC removal in Econ River water dosed with 7.5 mg/L ferrate (VI) (Appendix C-1, Table 14). This data suggests that both formulas remove about the same amount of DOC. A greater removal of DOC in river water than in wastewater was observed which probably reflected different chemical composition of the DOC in wastewater effluent versus Econ River water.

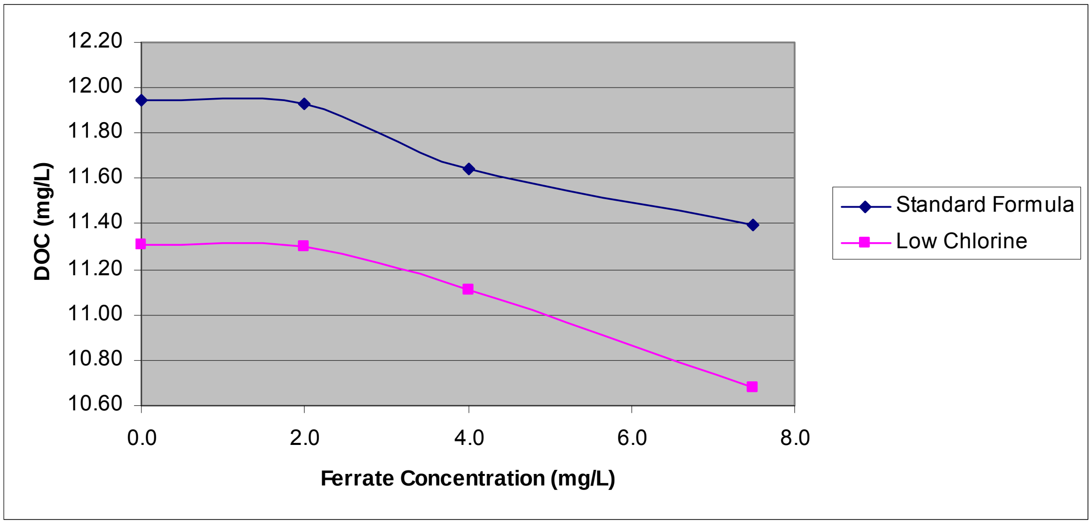


Figure 13: DOC Vs Ferrate (VI) Formula Concentrations in treated secondary wastewater

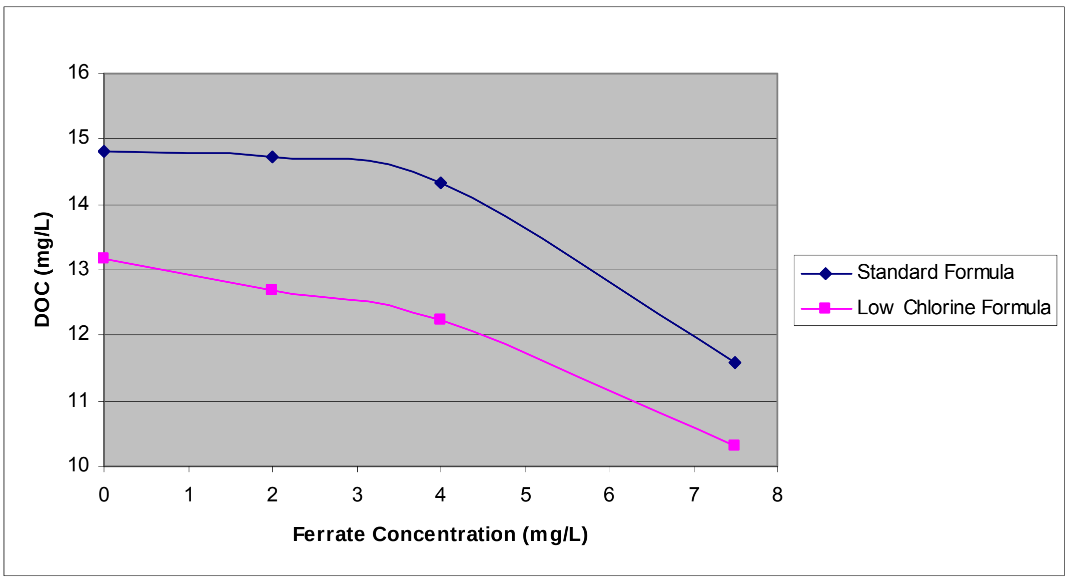


Figure 14: DOC Vs Ferrate (VI) Formula Concentrations in Econ River Water

4.5 Disinfection of Wastewater

The log removal of Enterococcus, *E. coli*, Total Coliform, and heterotrophic bacteria in wastewater after contact with ferrate (VI) for 30 minutes were calculated (Table 5). Both formulas were effective at removing Enterococcus, *E. coli*, and Total Coliform with an increasing removal as ferrate (VI) doses increase. Neither formula proved very effective at removing heterotrophic bacteria. At 7.5 mg/L, both formulas achieved over a 3-log removal of *E. Coli* and Total Coliform. Overall, the SCF proved to be a more effective disinfectant. As shown in Table 1, both formulas were successful at inactivating Enterococcus bacteria. Both ferrate formulations reduced the MPN/100mL of Enterococcus significantly at 7.5 mg/L.

Table 1: The mean and standard deviation (MPN/100mL) of Enterococcus bacteria at varying concentrations of ferrate addition with standard-chlorine and low-chlorine formula in wastewater

	Standard-Chlorine		Low-Chlorine	
Ferrate (VI) concentration (mg/L)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)
0.0	4.72E+03	4.12E+03	2.44E+03	1.60E+03
2.0	4.04E+03	4.77E+03	1.80E+03	604
4.0	77.3	69.3	578	276
7.5	16.3	3.08	82.6	276

As shown in Table 2, both ferrate (VI) formulas effectively disinfected the coliform bacteria present at 7.5 mg/L and achieved log removals of 3.6 (Table 5). The SCF also achieved a log removal of 3.56 at a lower dose of 4 mg/L.

Table 2: The mean and standard deviation (MPN/100mL) of Total Coliform at varying concentrations of ferrate addition with standard-chlorine and low-chlorine formula in wastewater

	Standard Chlorine		Low Chlorine	
Ferrate (VI) Concentration (mg/L)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)
0.0	5.40E+05	9.31E+05	9.95E+04	1.09E+05
2.0	1.25E+04	1.08E+04	1.08E+05	1.15E+05
4.0	149	125	9.74E+03	8.14E+03
7.5	131	238	22.7	7.10

As shown in Table 3, both ferrate (VI) formulas achieved less than one MPN/100mL of *E.Coli* at 7.5 mg/L.

Table 3: The mean and standard deviation (MPN/100mL) of E. coli at varying concentrations of ferrate addition with standard-chlorine and low-chlorine formula in wastewater

	Standard Chlorine		Low Chlorine	
Ferrate (VI) Concentration (mg/L)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)
0.0	4.04E+03	4.62E+03	3.48E+03	1.53E+03
2.0	3.85E+03	4.88E+03	1.95E+03	727
4.0	57.7	52.7	1113	546
7.5	0.25	0.50	0.75	0.50

The ferrate (VI) formulas removed heterotrophic bacteria but match less effectively than specific organisms used in this analysis (Table 4). The number of heterotrophic bacteria in diluted samples was not included. The diluted samples were consistently indicating higher counts of colony forming units per mL than non-diluted samples. Toxicity may have been the cause of this enumeration phenomenon, however there was no attempt to identify a possible toxin and its effect on the organisms.

Table 4: The mean and standard deviation (CFU/mL) of Heterotrophic bacteria at varying concentrations of ferrate addition with standard-chlorine and low-chlorine formula in wastewater

	Standard Chlorine		Low Chlorine	
Ferrate (VI) Concentration (mg/L)	Mean (CFU/mL)	Standard Deviation (CFU/mL)	Mean (CFU/mL)	Standard Deviation (CFU/mL)
0.0	2.64E+03	406	2.08E+03	2.43E+02
2.0	1.61E+03	241	1.94E+03	244
4.0	1.47E+03	188	1.67E+03	214
7.5	822	214	1.43E+03	477

Table 5: Log removals of microorganisms with Ferrate (VI) for wastewater effluent

	Enterococcus		E. Coli		Total Coliform		Heterotrophic Bacteria	
Ferrate (VI) Conc (mg/L)	Standard Formula log removal	Low Chlorine Formula log removal	Standard Formula log removal	Low Chlorine Formula log removal	Standard Formula log removal	Low Chlorine Formula log removal	Standard Formula log removal	Low Chlorine Formula log removal
Initial Conc	4.72E+03 MPN/ 100mL	2.44E+03 MPN/ 100mL	4.04E+03 MPN/ 100mL	3.48E+03 MPN/ 100mL	5.40E+05 MPN/ 100mL	9.95E+04 MPN/ 100mL	2.64E+03 CFU/ mL	2.08E+03 CFU/ mL
2	0.07	0.13	0.02	0.25	1.64	0.00	0.21	0.03
4	1.79	0.63	1.84	0.5	3.56	1.01	0.25	0.09
7.5	2.46	1.47	3.61	3.54	3.61	3.64	0.51	0.16

The number of bacteria of the two ferrate (VI) formulas (SCF and LCF) was compared statistically using a t-test (Steel and Torrie, 1960) at each concentration for each bacterium evaluated as shown in Table 6 (Refer to Appendix B-1). The confidence level for 2 mg/L ferrate (VI) for all organisms evaluated were 95 to 98% while some of the other concentrations were not as high and varied greatly. For example, at 7.5 mg/L ferrate (VI) the confidence level varied from 50 to 98%. These data suggest that the SCF was more effective at removing all experimental bacteria at 2 mg/L ferrate (VI) and Enterococcus and *E. coli* at 4 mg/L ferrate (VI) and only Enterococcus at 7.5 mg/L ferrate (VI) in wastewater.

Although the Hypothesis test suggests that the ferrate (VI) formulas had significant differences in terms of inactivating bacteria at 2 mg/L ferrate (VI), there was minimal log removal (Table 1) for these bacteria at this low ferrate (VI) dose for both formulas. Also, the Hypothesis test between the ferrate (VI) formulas for Heterotrophic bacteria is questionable since the toxicity may have influenced the enumeration as discussed previously. Furthermore, the t-test suggests that both ferrate (VI) formulas were significantly different at removing E.coli (Table 4) and Enterococcus (Table 2) from secondary wastewater at 4 mg/L ferrate (VI) but the initial quantity of *E. coli* and Enterococcus bacteria present was two orders of magnitude less than with Total Coliform (Table 3). Similarly, the t-test suggests that both ferrate (VI) formulas were significantly different at removing Enterococcus (Table 2) from secondary wastewater at 7.5 mg/L ferrate (VI) but as previously mentioned, the initial quantity of Enterococcus bacteria present was significantly lower than other bacterium, therefore it requires considerably less ferrate (VI) to disinfect Enterococcus than the other bacterium.

Table 6: Confidence Level for Hypothesis Test

	Confidence Level (%)			
Ferrate (VI) Concentration (mg/L)	Enterococcus	E. Coli	Total Coliform	Heterotrophs
2	98	98	95	98
4	90	98	<50	70
7.5	98	60	50	60

*Hypothesis: Bacteria removal is different for Ferrate (VI) formulas

4.6 Disinfection of Econ River Water

The $\log_{10}(N/N_0)$ of Enterococcus, *E. coli*, Total Coliform, and heterotrophic bacteria were calculated (Table 7). Both formulas were effective at disinfecting Enterococcus, *E. coli*, Total Coliform, and heterotrophic bacteria in Econ River water samples. The initial concentration of *E. coli* was zero with SCF experimentation and 8.6 MPN/100 mL with LCF experimentation in the untreated Econ River samples. This is considerably less than the reported average of 140 MPN/100mL of *E. coli* by the Saint Johns River Water Management District (SJRWMD, 2007). At 7.5 mg/L, both formulas showed almost equal disinfection effectiveness. A dose as low as 2 mg/L of SCF in Econ River water was an effective disinfectant at all dosages tested for Enterococcus, *E. coli*, Total Coliform, and heterotrophic bacteria. These ferrate (VI) formulas were considered effective disinfectants even though they did not achieve a three log removal for all these bacteria because the initial concentrations were significantly low enough to limit the amount of removal that could be achieved. Refer to the Appendix B-3 for the mean and standard deviations of the quantity of these bacteria pre- and post-ferrate (VI) addition of the SCF and LCF ferrate (VI) formulas in Econ River water.

Table 7: Log removals of Microorganisms in Econ River water treated with ferrate (VI)

	Enterococcus		E. Coli		Total Coliform		Heterotrophic Bacteria	
Ferrate (VI) Conc(mg/L)	Standard Formula log removal	Low Chlorine Formula log removal	Standard Formula log removal	Low Chlorine Formula log removal	Standard Formula log removal	Low Chlorine Formula log removal	Standard Formula log removal	Low Chlorine Formula log removal
Initial Conc	4.65 MPN/ 100mL	10.4 MPN/ 100mL	-	8.6 MPN/ 100mL	1.02E+03 MPN/ 100mL	162 MPN/ 100mL	1.00E+04 CFU/ mL	9.36E+03 CFU/ mL
2	≥0.67	0.19	-	≥0.93	≥3.01	1.69	2.40	1.95
4	≥0.67	0.83	-	≥0.93	≥3.01	≥2.21	2.35	2.37
7.5	≥0.67	≥1.01	-[1]	≥0.93	≥3.01	≥2.21	2.41	2.39

[1]Dashes (-) represent initial concentration was zero.
[2]Greater than or equal to symbol (≥) signifies post concentration was non-detected

The number of bacteria present post-treatment of the two ferrate (VI) formulas (SCF and LCF) was compared statistically using a t-test at each concentration for Enterococcus, Total Coliform, and heterotrophic bacteria as shown in Table 8 (Refer to Appendix B-2). The number of E. coli bacteria present post-treatment of the two ferrate (VI) formulas was unable to be compared statistically since there was no E. coli initially present in the untreated Econ River sample to be removed by the SCF ferrate (VI). The t-test suggests that the ferrate (VI) formulas were equally effective at inactivating bacteria at all concentrations except at 2 mg/L. The SCF was more effective at removing Enterococcus and heterotrophic bacteria in Econ River water at 2 mg/L ferrate (VI) dose. The confidence level for 2 mg/L ferrate (VI) were 95% for Enterococcus and Heterotrophic bacteria while the other concentrations were not as high.

Table 8: Confidence Level for Hypothesis Test

	Confidence Interval (%)		
Ferrate (VI) Concentration (mg/L)	Enterococcus	Total Coliform	Heterotrphs
2	95	70	95
4	60	60	70
7.5	60	60	60

*Hypothesis: Bacteria removal is different for Ferrate (VI) formulas

4.7 THM Formation

The sample chromatograms showed less than 15 ppb Total Trihalomethanes (TTHM) concentration (Table 9). Two samples of 7.5 mg/L of SCF ferrate (VI) were shown to contain 11-12 ppb chloroform. In most of the 4.0 and 2.0-mg/L samples treated with both formulas, a very small chloroform peak was evident. When these chloroform peaks were interpreted, it was determined that they corresponded to a chloroform concentration of 7 ppb or less. No brominated THMs were observed in any of the samples tested, therefore the TTHM value is equal to chloroform concentration.

Chloroform is the most volatile of the THMs and therefore the most difficult one to recover. The TTHM values in all samples are exceptionally low, if not negligible. The detection limit for the technique itself is on the order of 1 ppb using the current GC system used. The chloroform present in the ferrate (VI) dosed samples may be attributed to hypochlorite reacting with DOC during ferrate (VI) synthesis. This may be especially applicable to the SCF where excess hypochlorite is used in synthesis. Although the THM formation potential (THMFP) was not determined in this study, another study determined the THMFP of the Econ River to be 15.2 ppb as chloroform (Mukattash, 2007). Assuming the THMFP of untreated Econ River water was 15.2 ppb, ferrate (VI) formed chloroforms below the formation potential of chloroforms in Econ River therefore THMFP was reduced by both ferrate (VI) formulas.

Table 9: THM Formation of ferrate (VI) treated Econ River water

Formula	Ferrate Dosage, mg/L	$CHCl_3$ RT = 2.35 ppb	$CHCl_2Br$ RT = 3.38 ppb	$CHClBr_2$ RT = 5.8 ppb	$CHBr_3$ RT = 8.5 Ppb	TOTAL THMs ppb
Standard	7.5	11	< 1	< 1	< 1	11
Standard	7.5	12	< 1	< 1	< 1	12
Low Chlorine	7.5	< 1	< 1	< 1	< 1	< 1
Low Chlorine	7.5	< 1	< 1	< 1	< 1	< 1
Standard	4	< 1	< 1	< 1	< 1	< 1
Standard	4	2	< 1	< 1	< 1	2
Low Chlorine	4	< 1	< 1	< 1	< 1	< 1
Low Chlorine	4	5	< 1	< 1	< 1	5
Standard	2	7	< 1	< 1	< 1	7
Standard	2	< 1	< 1	< 1	< 1	< 1
Low Chlorine	2	5	< 1	< 1	< 1	5
Low Chlorine	2	5	< 1	< 1	< 1	5

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The intention of this research is to evaluate the disinfection capabilities of two different ferrate (VI) synthesis formulas (Low Chlorine (LCF) ferrate (VI) and Standard Chlorine (SCF) ferrate (VI)) in Econ River water and wastewater at varying dosages. Furthermore, this research aims to assess the chlorine residual, DOC concentration, and THM formation after ferrate (VI) addition for each formula. Overall the goal of this study is to evaluate the potential of each formula to be used for water and wastewater treatment. The following conclusions and recommendations from this research were made:

- Kinetic data:
  - First order decomposition of ferrate (VI) was observed over a 30-minute contact time. It is uncertain why ferrate (VI) exhibited first order kinetics. Future research should try and explain what is causing the observed first order kinetic behavior.
  - There was an instantaneous demand of ferrate (VI) in secondary wastewater. Ferrate (VI) is known to react with water, and also to auto-catalyze. We are uncertain whether these phenomena were active or not, or if some other mechanism was responsible such as reaction with organic matter or reduced inorganics. Future research should try and identify the mechanisms causing this instantaneous demand.

- Approximately double the amount of ferrate (VI) remaining after 30 minutes for the SCF was double the concentration remaining for the LCF.

- The chlorine residual resulting from a 7.5 mg/L ferrate (VI) dose in wastewater after a 30-minute contact time was:
    - LCF ferrate (VI): 0.2 to 0.6 mg/L Cl_2
    - SCF ferrate (VI): 0.8 to 1.4 mg/L Cl_2
    - This was measured using the DPD method and pH adjustment. The assumption is that the DPD reagent reacts with both ferrate and free chlorine. It is recommended that an alternative, more accurate, measurement technique to quantify ferrate, total oxidant, and total chlorine in wastewater should be identified, or the assumptions for the DPD method be verified.
- Dissolved Organic Carbon (DOC)
    - Both ferrate (VI) formulas decreased DOC by approximately 0.5 – 22% in Econ River water
    - Both ferrate (VI) formulas decreased DOC by approximately 0.1 – 5% in secondary wastewater
- Disinfection
    - SCF ferrate (VI) disinfected better at lower dosages than LCF ferrate (VI)
    - At 7.5 mg/L dose of both formulas, a 3-log removal of *E. Coli* and Total Coliform bacteria was observed

- In Econ River water, disinfection BDL was achieved by the SCF ferrate (VI) at a 2 mg/L ferrate (VI) dose for Total Coliform and Enterococcus bacteria. LCF resulted in disinfection BDL at a dose 4 mg/L for coliforms, and 7.5 mg/L for Enterococcus. HPC was reduced by 99.6% at a dose of 4 mg/L by both formulas (SCF and LCF).
- Both ferrate (VI) formulas were more effective at inactivating heterotrophic bacteria in Econ River water than wastewater. It is possible that bacteria located in the interior of activated sludge floc fragments were protected from disinfectant
- It is uncertain why diluted HPC samples were indicating higher counts of colony forming units per mL than non-diluted samples. It is recommended that further experimentation on matrix effects from wastewater be conducted to determine if there is something inhibitory in the samples that caused the dilution phenomena observed for HPC.
- LCF ferrate (VI) in Econ River water achieved the same results as the SCF ferrate (VI) but required a slightly higher dose of 4 mg/L ferrate (VI) versus 2 mg/L SCF ferrate (VI).
- T-test results suggest the SCF ferrate (VI) is a slightly better disinfectant that LCF ferrate (VI).
- It would be of great interest if future research could analyze ferrate (VI) disinfection capability for more disinfectant resistant organisms such as Giardia and Cryptosporidium

- Trihalomethanes

- Both ferrate (VI) formulas produced less than 15 ppb TTHM concentration.
- Both ferrate (VI) formulas were well below the MCL for THMs

APPENDIX A: PRELIMINARY DATA WITH FERRATE (VI)

A-1 Ferrate (VI) Reaction Order

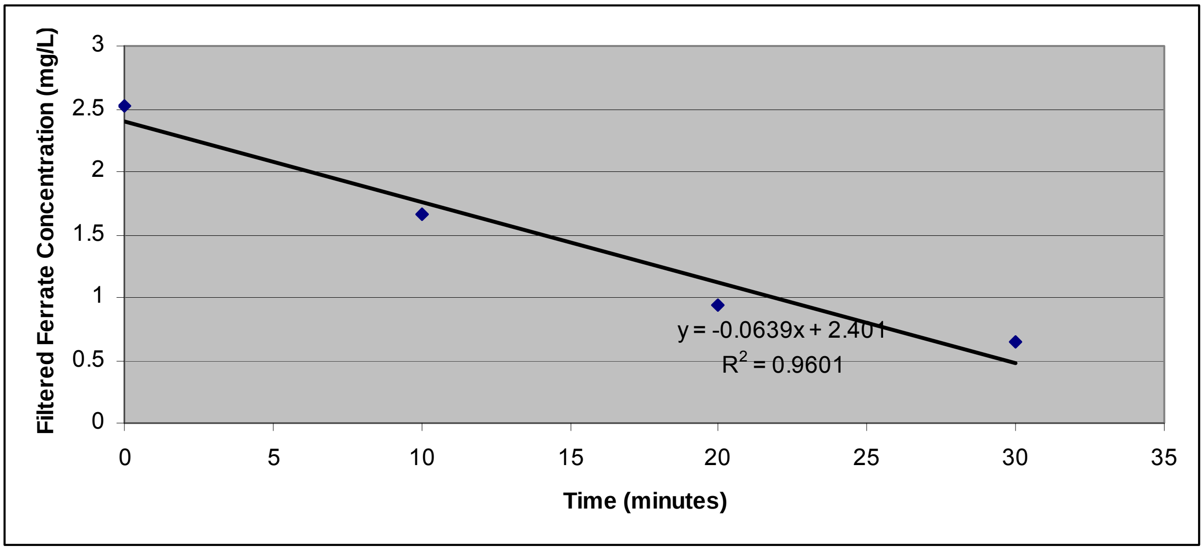


Figure 15: Zero Order Analysis of Averaged Ferrate (VI) concentration vs. Time for Low Chlorine Formula

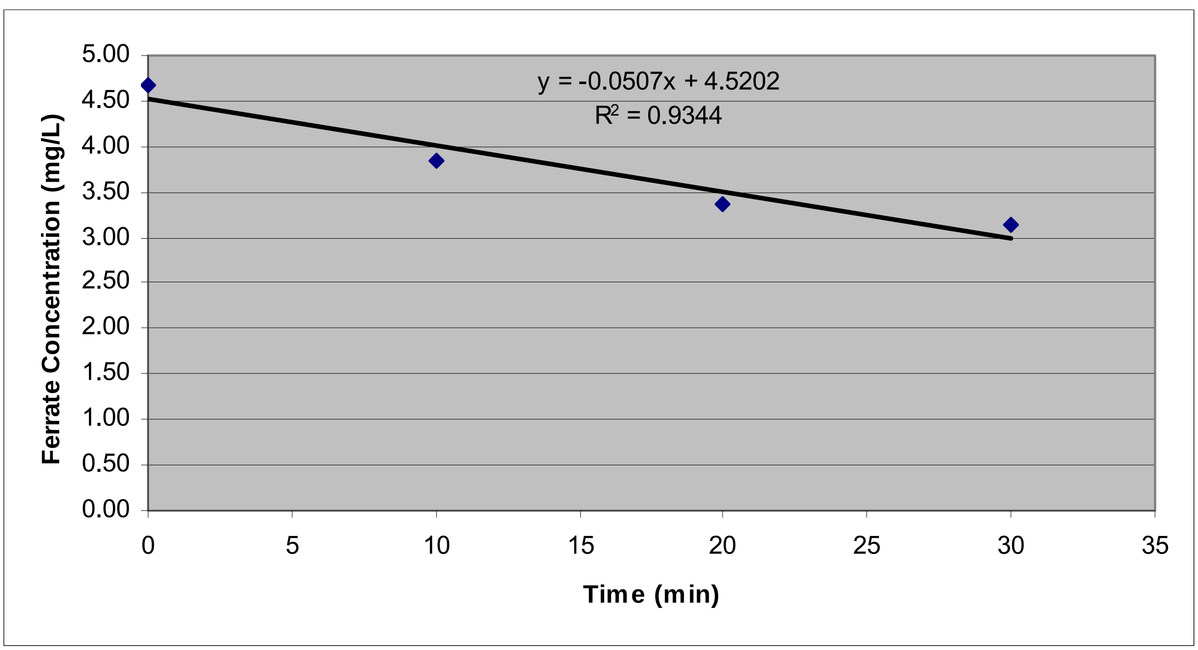


Figure 16: Zero Order Analysis of Averaged Ferrate (VI) concentration vs. Time for Standard Formula

A-2 Total Chlorine versus Ferrate Concentration of Standard and Low-Chlorine Formula in Wastewater and River Water

The Figures below demonstrate how the total chlorine increases with increasing doses of ferrate (VI) with Low Chlorine Formula and Standard Formula Ferrate (VI).

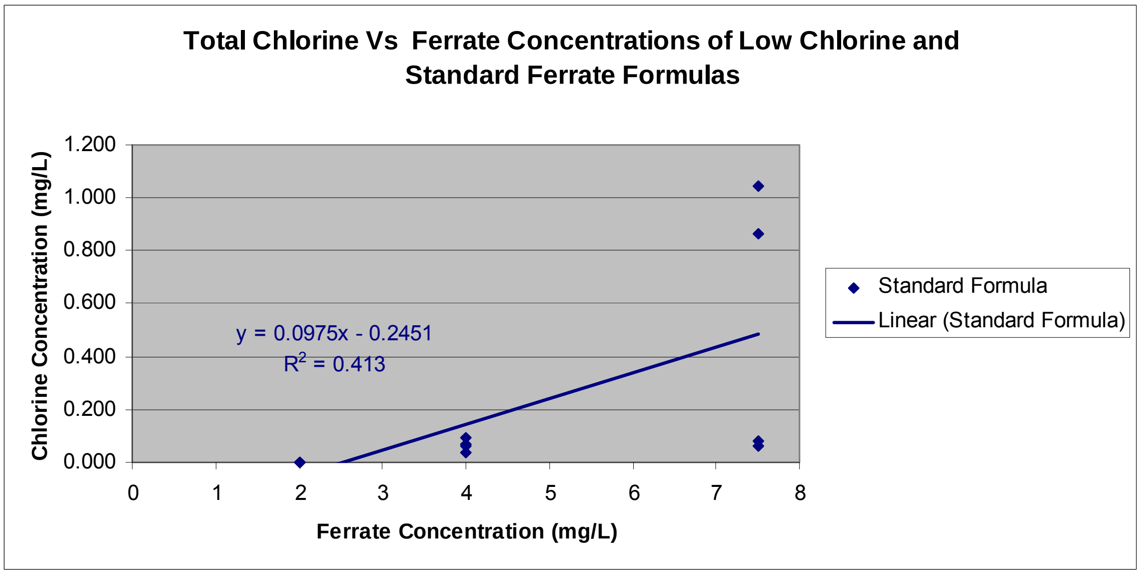


Figure 17: Total Chlorine vs. Ferrate Concentration in River Water

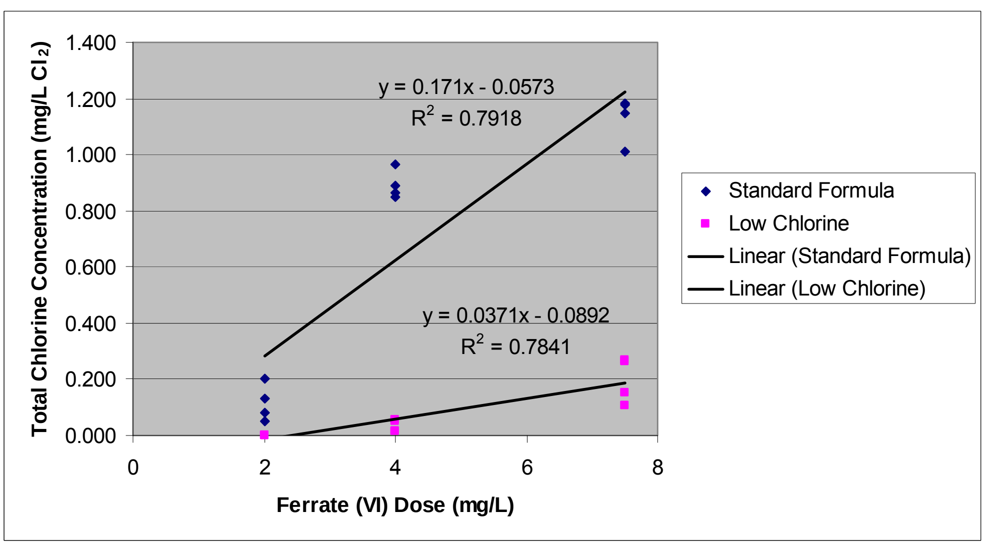


Figure 18: Total Chlorine vs. Ferrate Concentration in Wastewater

APPENDIX B: SUMMARY OF STATISTICS

B-1 T-Test for Wastewater

Hypothesis Test for Enterococcus Bacteria in Wastewater

Enterococcus Bacteria For Standard Formula			Enterococcus Bacteria For Low Chlorine Formula			
Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Delta (Std-Low)
	0	2419.6		0	261.3	2158.3
	0	2419.6		0	2419.6	0
	2	1180		2	2750	-1570
0-B	2	2300	0-A	2	2030	270
	0	533.5		0	1299.7	-766.2
	2	100		2	1340	-1240
	2	400		2	1340	-940
	0	533.5		0	1986.3	-1452.8
	0	2419.6		0	1986.3	433.3
	2	302		2	3130	-2828
2-B	2	102	2-A	2	1600	-1498
	0	10.4		0	461.1	-450.7
	0	16.4		0	816.4	-800
4-B	0	14.1	4-A	0	1119.9	-1105.8
	0	18.3		0	156.5	-138.2
	0	12.1		0	113	-100.9
	0	18.9		0	190.4	-171.5
7.5-B	0	16	7.5-A	0	285.1	-269.1

Hypothesis Test for Enterococcus Bacteria in Wastewater

$\sum(X1-X2)^2$	s^2	s	df	d	t_{obs}= d/s	Abs (t_{obs})	t-table	Confidence Interval level, %
7196059	584324.1	764.4109	3	214.575	0.28	0.28	-	<50
15548227	136344.6	369.2486	6	-1184.53	-3.21	3.21	3.143	98.00
2065924	35815.56	189.25	2	-785.5	-4.15	4.15	2.920	90.00
131107.1	1300.757	36.06601	3	-169.925	-4.71	4.71	4.541	98.00

Hypothesis Test for E. Coli in Wastewater Continued

E. Coli For Standard Formula			E. coli For Low Chlorine Formula			
Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Delta (Std-Low)
	0	866.4		0	2419.6	-1553.2
	0	1299.7		0	2419.6	-1119.9
	2	1100		2	2460	-1360
0-B	2	960	0-A	2	3180	-2220
	0	193.5		0	2419.6	-2226.1
	2	520		2	1090	-570
	2	740		2	940	-200
	0	56		0	2419.6	-2363.6
	0	57.6		0	2419.6	-2362
	2	100		2	198630	-198530
2-B	2	630	2-A	2	241960	-241330
	0	1		0	1732.9	-1731.9
	0	2		0	1413.6	-1411.6
4-B	0	1	4-A	0	1119.9	-1118.9
	0	1		0	1	0
	0	1		0	1	0
	0	1		0	1	0
7.5-B	0	1	7.5-A	0	1	0

Hypothesis Test for E. Coli in Wastewater Continued

$\sum(X1+X2)^2$	s^2	s	df	d	t_{obs}= d/s	Abs (t_{obs})	t-table	Confidence Interval level, %
1.04E+07	5.58E+04	236.17	3	-1563.28	-6.62	6.62	5.84	99.00
9.77E+10	1.64E+09	40547.54	6	-63940.24	-1.58	1.58	1.44	98.00
6244029.38	31335.24	177.02	2	-1420.80	-8.03	8.03	6.97	98.00
0.00	0.00	0.00	3	0.00	1.00	1.00	0.98	60.00

Hypothesis Test for Total Coliform in Wastewater

Total Coliform For Standard Formula			Total Coliform For Low Chlorine Formula			
Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Delta (Std-Low)
	0	2419.6		0	2419.6	0
	0	2419.6		0	2419.6	0
	2	198630		2	2419.6	196210.4
0-B	2	241960	0-A	2	198630	43330
	0	2419.6		0	2419.6	0
	2	22470		2	241960	-219490
	2	30760		2	173290	-142530
	0	2419.6		0	2419.6	0
	0	2419.6		0	2419.6	0
	2	17890		2	198630	-180740
2-B	2	23820	2-A	2	241960	-218140
	0	9.4		0	2419.6	2410.2
	0	55.2		0	2419.6	2364.4
4-B	0	59.2	4-A	0	2419.6	2360.4
	0	488.4		0	24.6	-463.8
	0	5.2		0	27.5	22.3
	0	18.7		0	26.5	7.8
7.5-B	0	13.5	7.5-A	0	12.2	-1.3

Hypothesis Test for Total Coliform in Wastewater Continued

$\sum(X1+X2)^2$	s^2	s	df	d	t_{obs}= d/s	Abs (t_{obs})	t-table	Confidence Interval level, %
4.04E+10	2.17E+09	46575.31	3.00	59885.10	1.29	1.29	1.25	70.00
1.49E+11	1.57E+09	39651.11	6.00	-108700.00	-2.74	2.74	2.45	95.00
1.70E+07	1.41E+07	3760.68	2.00	2378.33	0.63	0.63	-	<50
2.16E+05	1.40E+04	118.45	3.00	-108.75	-0.92	0.92	0.77	50.00

Hypothesis Test for Heterotrophic Bacteria in Wastewater

HPC for Standard Formula B					HPC for Low Chlorine Formula A					
Conc.(mg/l)	Dilution, (10^n)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for Dilution	Conc.(mg/l)	Dilution, (10^n)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for Dilution	Delta (Std-Low)
	0	1	308	3080		0	1	224	2240	840
	0	1	256	2560		0	1	180	1800	760
0-B	0	1	228	2280	0-A	0	1	220	2200	80
	0	1	188	1880		0	1	196	1960	-80
	0	1	152	1520		0	1	196	1960	-440
	0	1	144	1440		0	1	224	2240	-800
	1	2	148	14800		1	2	192	19200	-4400
	1	2	56	5600		1	2	91	9100	-3500
	0	1	160	1600		0	1	168	1680	-80
	0	1	192	1920		0	1	164	1640	280
	0	1	132	1320		0	1	216	2160	-840
	1	2	53	5300		1	2	112	11200	-5900
	1	2	63	6300		1	2	140	14000	-7700
2-B	1	2	59	5900	2-A	1	2	115	11500	-5600
	0	1	160	1600		0	1	152	1520	80
	0	1	148	1480		0	1	192	1920	-440
	0	1	168	1680		0	1	164	1640	40
	1	2	40	4000		1	2	92	9200	-5200
	1	2	75	7500		1	2	63	6300	1200
	1	2	42	4200		1	2	62	6200	-2000
	0	1	116	1160		0	1	136	1360	-200
	0	1	156	1560		0	1	172	1720	-160
4-B	0	1	136	1360	4-A	0	1	188	1880	-520
7.5-B	0	1	120	1200	7.5-A	0	1	128	1280	-80

Hypothesis Test for Heterotrophic Bacteria in Wastewater Continued

0	1	59	590		0	1	196	1960	-1370
0	1	84	840		0	1	104	1040	-200

Delta (Std-Low)	$\sum(X1+X2)^2$	s^2	s	df	d	$t_{observed}$= d/s	Abs($t_{observed}$)	t-table	Confidence Interval level, %
840									
760									
80	1289600	58133.3333	241.10855	2	560	2.32	2.32	1.886	80.00
-80									
-440									
-800									
-4400									
-3500									
-80									
280									
-840									
-5900									
-7700									
-5600	158700400	748647.934	865.24444	10	-2641.8182	-3.05	3.05	2.764	98.00
80									
-440									
40									
-5200									
1200									
-2000									
-200	33017600	376790.123	613.83233	8	-800	-1.30	1.30	1.108	70.00

Hypothesis Test for Heterotrophic Bacteria in Wastewater Continued

-160									
-520									
-80									
-1370									
-200	1923300	169300	411.46081	2	-550	-1.34	1.34	1.061	60.00

B-2 T-Test for River Water

Hypothesis Test for Enterococcus Bacteria in Wastewater

Enterococcus Bacteria For Standard Formula			Enterococcus Bacteria For Low Chlorine Formula			
Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Conc.(mg/l)	Dilution	MPN/100ml Accounting for Dilution	Delta (Std-Low)
0	0	5.2	0	0	12.2	-7
0	0	4.1	0	0	8.5	-4.4
2	0	1	2	0	5.2	-4.2
2	0	1	2	0	9.8	-8.8
2	0	1	2	0	8.6	-7.6
2	0	1	2	0	3.1	-2.1
4	0	1	4	0	1	0
4	0	1	4	0	1	0
4	0	1	4	0	1	0
4	0	1	4	0	3.1	-2.1
7.5	0	1	7.5	0	1	0
7.5	0	1	7.5	0	1	0
7.5	0	1	7.5	0	1	0
7.5	0	1	7.5	0	1	0

Hypothesis Test for Enterococcus Bacteria in Wastewater Continued

$\sum(X1-X2)^2$	s^2	s	df	d	$t_{observed}$= d/s	Abs ($t_{observed}$)	t-table	Confidence Interval level, %
68.36	1.69	1.30	1	-5.70	-4.38	4.38	3.078	80.00
157.25	2.37	1.54	3	-5.68	-3.69	3.69	3.182	95.00
4.41	0.28	0.53	3	-0.53	-1.00	1.00	0.978	60.00
0	0.00	0.00	3	0.00	1.00	1.00	0.978	60.00

Hypothesis Test for Total Coliform in Wastewater

Total Coliform For Standard Formula			Total Coliform For Low Chlorine Formula			
Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Delta (Std-Low)
0	0	2419.6	0	0	186	2233.6
0	0	1299.7	0	0	137.4	1162.3
2	0	253	2	0	5.2	247.8
2	0	120	2	0	1	119
2	0	1	2	0	4.1	-3.1
2	0	1	2	0	3	-2
4	0	1	4	0	1	0
4	0	1	4	0	1	0
4	0	1	4	0	1	0
4	0	1	4	0	1	0
7.5	0	1	7.5	0	1	0
7.5	0	1	7.5	0	1	0
7.5	0	1	7.5	0	1	0
7.5	0	1	7.5	0	1	0

Hypothesis Test for Total Coliform in Wastewater Continued

$\sum(X1-X2)^2$	s^2	s	df	d	$t_{observed}$= d/s	Abs ($t_{observed}$)	t-table	Confidence Interval level, %
6339910.3	286920.9	535.7	1	1697.95	3.17	3.17	3.078	80.00
75579.5	3572.7	59.8	3	90.43	1.51	1.51	1.250	70.00
0.0	0.0	0.0	3	0.00	1.00	1.00	0.978	60.00
0.0	0.0	0.0	3	0.00	1.00	1.00	0.978	60.00

Hypothesis Test for Heterotrophic Bacteria in Wastewater

HPC for Standard Formula B					HPC for Low Chlorine Formula A					
Conc. (mg/l)	Dilution, (10^n)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for Dilution	Conc. (mg/l)	Dilution, (10^n)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for Dilution	Delta (Std-Low)
	0	1	180	1800		0	1	140	1400	400
	0	1	188	1880		0	1	188	1880	0
0-B	0	1	124	1240	0-A	0	1	124	1240	0
	0	0	45	45		0	0	65	65	-20
	0	0	32	32		0	0	95	95	-63
	0	0	42	42		0	0	70	70	-28
	0	0	19	19		0	0	63	63	-44
	0	0	35	35		0	0	100	100	-65
2-B	0	0	30	30	2-A	0	0	40	40	-10
	0	0	18	18		0	0	9	9	9
	0	0	22	22		0	0	18	18	4
	0	0	22	22		0	0	17	17	5
	0	0	17	17		0	0	14	14	3
	0	0	61	61		0	0	9	9	52
4-B	0	0	13	13	4-A	0	0	16	16	-3
	0	0	35	35		0	0	19	19	16
	0	0	31	31		0	0	34	34	-3
	0	0	30	30		0	0	72	72	-42
	0	0	52	52		0	0	25	25	27
	0	0	40	40		0	0	43	43	-3
7.5-B	0	0	34	34	7.5-A	0	0	36	36	-2

Hypothesis Test for Heterotrophic Bacteria in Wastewater

Delta (Std-Low)	$\sum(X1+X2)^2$	s^2	s	df	d	$t_{observed}$= d/s	Abs ($t_{observed}$)	t-table	Confidence Interval level, %
400									
0									
0	160000	17777.78	133.33	1.00	133.33	1.00	1.00	1.000	50.00
-20									
-63									
-28									
-44									
-65									
-10	11414	135.47	11.64	5.00	-38.33	-3.29	3.29	2.571	95.00
9									
4									
5									
3									
52									
-3	2844	74.13	8.61	5.00	11.67	1.36	1.36	1.156	70.00
16									
-3									
-42									
27									
-3									
-2	2771	92.09	9.60	5.00	-9.67	-1.01	1.01	0.920	60.00

B-3 River Water Statisitcs

Table 10: The mean and standard deviation (MPN/100 mL) of Total Coliform at varying concentrations of Ferrate (VI) addition with the Standard Formula and Low Chlorine Formula Ferrate (VI) in Econ River water

	Standard		Low-Chlorine	
Concentration (mg/L)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)
0.0	1.02E+03	1.07E+03	162	34.4
2.0	nd	N/A	3.33	1.79
4.0	nd	N/A	nd	N/A
7.5	nd	N/A	nd	N/A

* nd means not detectable

Table 11: The mean and standard deviation (MPN/100 mL) of E. coli at varying concentrations of ferrate addition with the Standard Formula and Low Chlorine Formula Ferrate (VI) in Econ River water

	Low-Chlorine	
concentration (mg/L)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)
0.0	8.60	0.00
2.0	nd	nd
4.0	nd	nd
7.5	nd	nd

* nd means not detectable

Table 12: The mean and standard deviation (CFU/mL) of Heterotrophic bacteria at varying concentrations of ferrate (VI) addition with the Standard Formula and Low Chlorine Formula Ferrate (VI) in Econ River water

	Standard Chlorine		Low-Chlorine	
Concentration (mg/L)	Mean (CFU/mL)	Standard Deviation (CFU/mL)	Mean (CFU/mL)	Standard Deviation (CFU/mL)
0.0	1.00E+04	7.35E+03	9.36E+03	6.72E+03
2.0	39.4	19.4	106.1	51.9
4.0	44.4	33.8	40.3	30.1
7.5	39.2	9.07	38.3	28.6

Table 13: The mean and standard deviation (MPN/100 mL) of Enterococcus at varying concentrations of ferrate addition with the Standard Formula and Low Chlorine Formula Ferrate (VI) in Econ River water

	Standard Chlorine		Low-Chlorine	
Ferrate (VI) Concentration (mg/L)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)	Mean (MPN/100mL)	Standard Deviation (MPN/100mL)
0.0	4.65	0.78	10.4	2.62
2.0	nd	N/A	6.68	3.08
1.0	nd	N/A	0.78	1.55
7.5	nd	N/A	0.50	0.71

* nd means not detectable

APPENDIX C: RAW EXPERIMENTAL DATA

C-1 Preliminary Dissolved Organic Carbon Data

Table 14: DOC percent removal

	ΔDOC Wastewater (%)		ΔDOC Econ River water (%)	
Ferrate (VI) concentration (mg/L)	Standard Formula	Low Chlorine Formula	Standard Formula	Low Chlorine Formula
2.0	0.2	0.1	0.5	3.7
4.0	2.5	1.8	3.2	7.1
7.5	4.6	5.6	22	22

<u>Standard Formula</u>

Preliminary DOC Wastewater Data for Standard Formula at pH 6

Standard Curve	
Known DOC Concentration (mg/L C)	Counts
0	164526
0	154894
0	105163
0	103124
0	93131
0	98276
0.5	518443
0.5	501619
0.5	508398
1	965885
1	959653
1	961044
2	1739371
2	1760969
2	1753055
5	3943585
5	3930474
5	3959157
10	7381764
10	7432505
10	7399976
0	89040
0	87801
0	82794

DOC of Standard Formula in wastewater at pH 6

DATA: pH 6				
Sample	Counts	Concentration from Standard Curve (mg/L DOC)	Concentration from DOC Instrument (mg/L DOC)	Average DOC (mg/L)
Wastewater Rep 1	6229200	8.28	6.49	
Wastewater Rep 1	6166089	8.19	6.42	
Wastewater Rep 1	6243689	8.30	6.50	
Wastewater Rep 2	6389990	8.50	6.66	
Wastewater Rep 2	6398548	8.51	6.67	
Wastewater Rep 2	6260860	8.32	6.52	6.54
Formula B Run 1 Rep 1	6039180	8.02	6.29	
Formula B Run 1 Rep 1	5994231	7.96	6.24	
Formula B Run 1 Rep 1	5887738	7.81	6.13	
Formula B Run 1 Rep 2	5954765	7.90	6.20	
Formula B Run 1 Rep 2	5929917	7.87	6.18	
Formula B Run 1 Rep 2	5845786	7.75	6.09	6.19
Formula B Run 2 Rep 1	5507928	7.29	5.74	
Formula B Run 2 Rep 1	5413793	7.16	5.64	
Formula B Run 2 Rep 1	5473099	7.24	5.70	
Formula B Run 2 Rep 2	5607035	7.43	5.84	
Formula B Run 2 Rep 3	5541856	7.34	5.77	
Formula B Run 2 Rep 4	5479747	7.25	5.71	5.73

DOC of Standard Formula in wastewater at unadjusted pH

Sample ID	Counts	Dissloved Organic Carbon Concentration (mg/L)	Dilution Factor	Concentration of Dissolved Carbon Accounting for Dilution, ppm	Average
Untreated WW Rep 1	7852578	8.18	1	8.18	
Untreated WW Rep 1	7906950	8.24	1	8.24	
Untreated WW Rep 1	7316334	7.62	1	7.62	
Untreated WW Rep 2	8317076	8.66	1	8.66	
Untreated WW Rep 2	7854696	8.18	1	8.18	
Untreated WW Rep 2	8052429	8.39	1	8.39	8.21
Diluted Untreated WW Rep 1	4235451	4.41	2	8.82	
Diluted Untreated WW Rep 1	4091046	4.26	2	8.52	
Diluted Untreated WW Rep 1	4455890	4.64	2	9.28	8.88
Unadjusted Run 1 Replicate 1	6443845	6.71	1	6.71	
Unadjusted Run 1 Replicate 1	6415228	6.68	1	6.68	
Unadjusted Run 1 Replicate 1	6526606	6.80	1	6.80	
Unadjusted Run 1 Replicate 2	6476667	6.75	1	6.75	
Unadjusted Run 1 Replicate 2	6421374	6.69	1	6.69	
Unadjusted Run 1 Replicate 2	6491665	6.76	1	6.76	6.73
Diluted Unadjusted Run 1	3321758	3.46	2	6.92	
Diluted Unadjusted Run 1	3018357	3.14	2	6.29	
Diluted Unadjusted Run 1	3268363	3.40	2	6.81	6.67
Unadjusted Run 2 Replicate 1	6211460	6.47	1	6.47	
Unadjusted Run 2 Replicate 1	6307211	6.57	1	6.57	
Unadjusted Run 2 Replicate 1	6469696	6.74	1	6.74	
Unadjusted Run 2 Replicate 2	6328749	6.59	1	6.59	
Unadjusted Run 2 Replicate 2	6277031	6.54	1	6.54	
Unadjusted Run 2 Replicate 2	6291970	6.55	1	6.55	6.59
Diluted Unadjusted Run 2	3312311	3.45	2	6.90	
Diluted Unadjusted Run 2	3255408	3.39	2	6.78	
Diluted Unadjusted Run 2	3035702	3.16	2	6.32	6.67

Low-Chlorine Formula

Preliminary DOC Wastewater Data for Low Chlorine Formula at pH 6

Objective: Measure DOC of pH 6 experiment samples

Standard Curve	
0	164526
0	154894
0	105163
0	103124
0	93131
0	98276
0.5	518443
0.5	501619
0.5	508398
1	965885
1	959653
1	961044
2	1739371
2	1760969
2	1753055
5	3943585
5	3930474
5	3959157
10	7381764
10	7432505
10	7399976
0	89040
0	87801
0	82794

DOC of Low Chlorine Formula in wastewater at pH 6

DATA				
Sample	Counts	Concentration from Standard Curve (mg/L DOC)	Concentration from DOC Instrument (mg/L DOC)	Average
Formula A Run 1 Rep 1	5142547	4.46	5.36	
Formula A Run 1 Rep 1	5257696	4.62	5.48	
Formula A Run 1 Rep 1	5173351	4.50	5.39	
Formula A Run 1 Rep 2	5274675	4.64	5.49	
Formula A Run 1 Rep 2	5307312	4.69	5.53	
Formula A Run 1 Rep 2	5221795	4.57	5.44	5.45
Formula A Run 2 Rep 1	4848963	4.06	5.05	
Formula A Run 2 Rep 1	4762571	3.94	4.96	
Formula A Run 2 Rep 1	4857124	4.07	5.06	
Formula A Run 2 Rep 2	4748196	3.92	4.95	
Formula A Run 2 Rep 2	4794519	3.98	4.99	
Formula A Run 2 Rep 2	4676206	3.82	4.87	4.98
Wastewater Rep 1	6229200	5.95	6.49	
Wastewater Rep 1	6166089	5.86	6.42	
Wastewater Rep 1	6243689	5.97	6.50	
Wastewater Rep 2	6389990	6.17	6.66	
Wastewater Rep 2	6398548	6.18	6.67	
Wastewater Rep 2	6260860	5.99	6.52	6.54

Standard Curve DOC Data for Low Chlorine Formula at unadjusted pH

Objective: Measure DOC of unadjusted pH experiment samples

Sample ID	Counts	Known Carbon Concentration (mg/L)
DI	503137	0
DI	393948	0
DI	400250	0
DI	400999	0
DI	381036	0
DI	467669	0
0.5 ppm C	906588	0.5
0.5 ppm C	906692	0.5
0.5 ppm C	881278	0.5
1 ppm C	1551386	1
1 ppm C	1525504	1
1 ppm C	1289070	1
2 ppm C	2527198	2
2 ppm C	2506461	2
2 ppm C	2314650	2
5 ppm C	5559245	5
5 ppm C	5797654	5
5 ppm C	5947039	5
10 ppm C	10603354	10
10 ppm C	9924860	10
10 ppm C	10928446	10
20 ppm C	22495884	20
20 ppm C	20668273	20
20 ppm C	22577518	20

DOC of Low Chlorine Formula in wastewater at unadjusted pH

Sample ID	Counts	Dilution Factor	Concentration Using Standard Curve, ppm	Concentration of Dissolved Carbon Accounting for Dilution, ppm	Average
Ferrate/FilteredWW Run 1-Rep 1	11005727	1.00	10.66	10.66	
Ferrate/FilteredWW Run 1-Rep 1	10897692	1.00	10.55	10.55	
Ferrate/FilteredWW Run 1-Rep 1	10665160	1.00	10.32	10.32	
Ferrate/FilteredWW Run 1-Rep 2	10648368	1.00	10.30	10.30	
Ferrate/FilteredWW Run 1-Rep 2	10430842	1.00	10.09	10.09	
Ferrate/FilteredWW Run 1-Rep 2	9825691	1.00	9.48	9.48	10.23
Untreated WW Rep 1	11477443	1.00	11.13	11.13	
Untreated WW Rep 1	11058159	1.00	10.71	10.71	
Untreated WW Rep 1	10905718	1.00	10.56	10.56	
Untreated WW Rep 2	11634034	1.00	11.29	11.29	
Untreated WW Rep 2	12238036	1.00	11.89	11.89	
Untreated WW Rep 2	12065872	1.00	11.72	11.72	11.22

Standard Curve DOC Data for Low Chlorine Formula at unadjusted pH

Standard Curve	
Known Carbon Concentration (mg/L)	Counts
0	65746
0	452598
0	880329
0	3533
0	562670
0	386146
0.5	323284
0.5	378520
0.5	43569
1	4244
1	824483
1	3350
2	2122138
2	1823745
5	5170311
5	7432823
5	5010270
20	20170384
20	19591411
20	20547535
10	9725759
10	9862224
10	9356512
0	428383
0	403061
0	396555

DOC of Low Chlorine Formula in wastewater at unadjusted pH

Sample	Counts	Dilution factor	Dissolved Organic Carbon Concentration (mg/L)	Average Dissolved Organic Carbon Concentration (mg/L)
FWW Replicate 1	12099083	1	12.04	
FWW Replicate 1	12094012	1	12.03	
FWW Replicate 1	11801324	1	11.74	
FWW Replicate 2	12270029	1	12.21	
FWW Replicate 2	12510020	1	12.45	
FWW Replicate 2	11727233	1	11.66	12.02
Unadjusted Run 2 Replicate 1	10926402	1	10.86	
Unadjusted Run 2 Replicate 1	9800425	1	9.73	
Unadjusted Run 2 Replicate 1	11576321	1	11.51	
Unadjusted Run 2 Replicate 1	11366730	1	11.30	
Unadjusted Run 2 Replicate 1	10130482	1	10.06	10.64

Unadjusted Run 2 Replicate 1	10427616	1	10.36	

C-2 Wastewater Kinetics

Standard Formula Kinetics

Date: 3/4/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Standard Formula (B) Ferrate in wastewater over 30 minutes

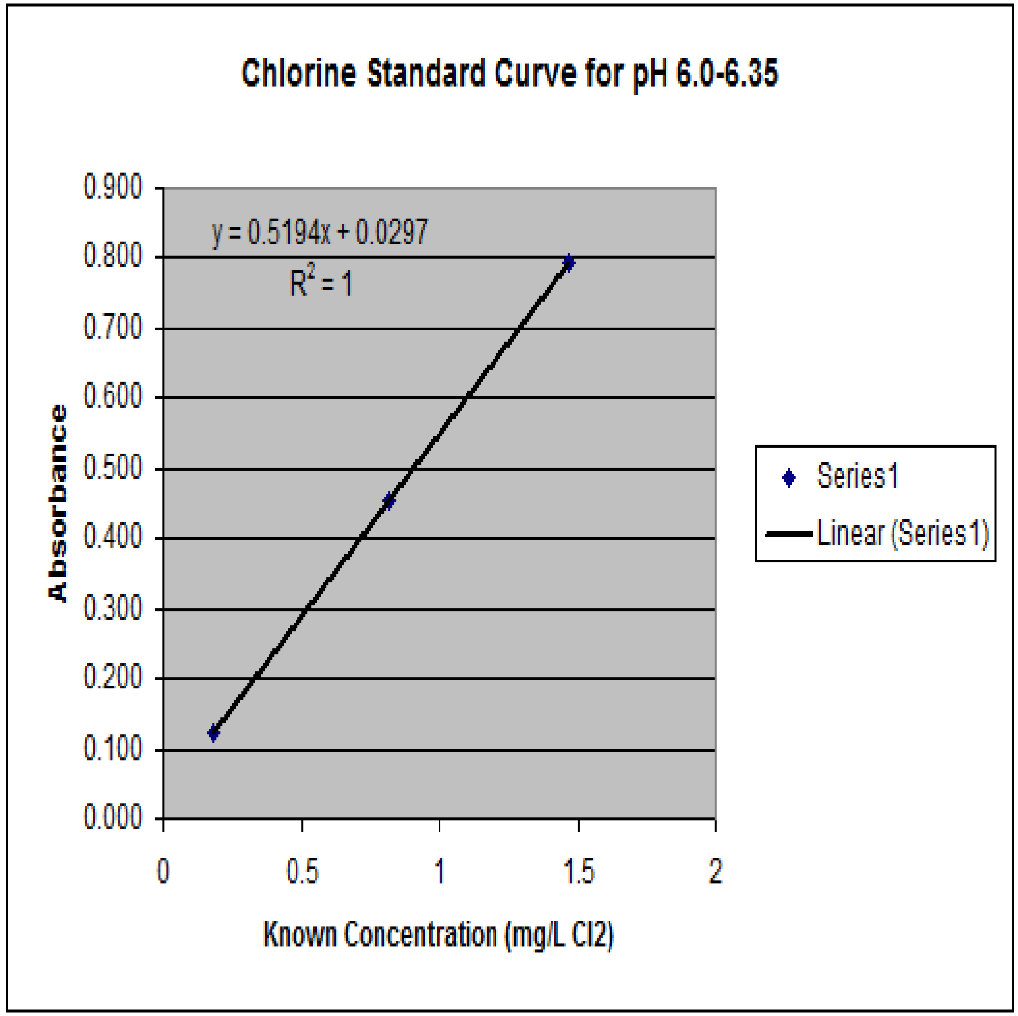
Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.012
Filtered Wastewater		0.008

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	-0.026
Wastewater with DPD	-0.005
Filtered Wastewater with DPD	0.016
Blank Gel	0.040
Std. 1	0.139
Std. 2	0.472
Std. 3	0.809

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.123	0.18
Std. 2	0.456	0.82
Std. 3	0.793	1.47



The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1:
Raw Data

		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH			Ferrate Absorbance based on DI water as zero at 510nm, pH 6-6.35				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time	pH	Rep1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	9.57	0.085	0.089	0.057	0.049	1.560	1.561	6.10	0.048	0.049	0.008	0.007	0.506	0.342
10	9.60	0.097	0.095	0.044	0.047	1.312	0.915	6.00	0.039	0.041	0.001	-0.005	0.397	0.574
20	9.56	0.060	0.063	0.036	0.040	1.245	1.218	6.10	0.037	0.040	0.009	0.006		
30	9.56	0.051	0.052	0.039	0.035	0.872	0.571	6.10	0.023	0.020	0.008	0.005	0.368	0.402

Table 2:
Absorbances for WW

		Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm			Ferrate Absorbance Adjusted for wastewater at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	9.57	0.073	0.077	0.049	0.041	1.544	1.545	6.10	0.036	0.037	0.000	-0.001	0.490	0.326
10	9.60	0.085	0.083	0.036	0.039	1.296	0.899	6.00	0.027	0.029	-0.007	-0.013	0.381	0.558
20	9.56	0.048	0.051	0.028	0.032	1.229	1.202	6.10	0.025	0.028	0.001	-0.002		
30	9.56	0.039	0.040	0.031	0.027	0.856	0.555	6.10	0.011	0.008	0.000	-0.003	0.352	0.386

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm							Ferrate Concentration (mg/L) at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt			pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0	9.57	7.59	8.00	5.09	4.26			6.10	3.74	3.84	0.00	-0.10	0.886	0.570
10	9.60	8.83	8.62	3.74	4.05			6.00	2.81	3.01	-0.73	-1.35	0.676	1.017
20	9.56	4.99	5.30	2.91	3.33			6.10	2.60	2.91	0.10	-0.21		
30	9.56	4.05	4.16	3.22	2.81			6.10	1.14	0.83	0.00	-0.31	0.621	0.686

Date: 3/4/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Standard Formula (B) Ferrate in wastewater over 30 minutes

Spectrasuite

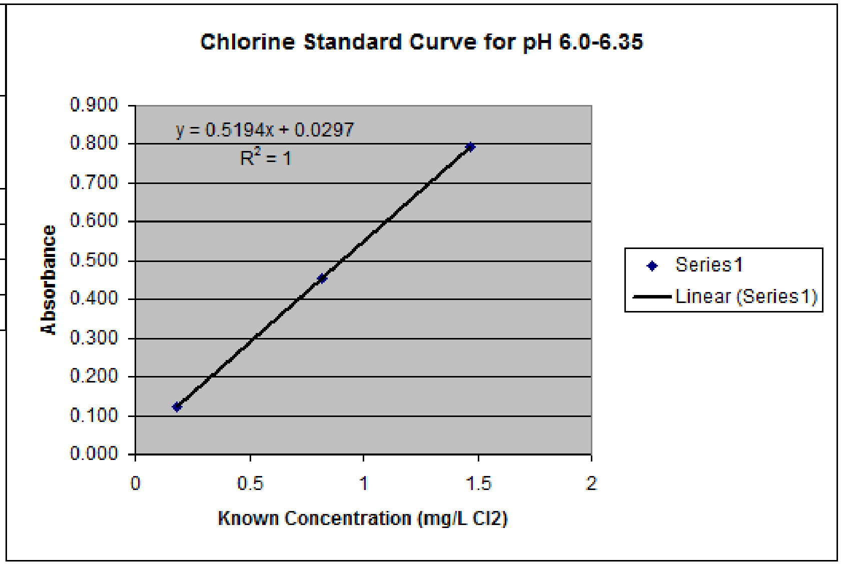
Zero-DI water		Absorbance
Wastewater		0.012
Filtered Wastewater		0.008

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	-0.026

Wastewater with DPD	-0.005
Filtered Wastewater with DPD	0.016
Blank Gel	0.040
Std. 1	0.139
Std. 2	0.472
Std. 3	0.809

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.123	0.18
Std. 2	0.456	0.82
Std. 3	0.793	1.47



Potassium Ferrate Standard Curve with DPD at 530 nm Equation: y=0.0547x+0.1154

The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH			Ferrate Absorbance based on DI water as zero at 510nm, pH 6-6.35				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Repl 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	9.70	0.103	0.102	0.056	0.050	1.936	2.218	6.10	0.058	0.055	0.007	0.006	0.789	0.830
10	9.70	0.110	0.117	0.041	0.048	1.274	1.531	6.10	0.071	0.072	0.009	0.015	0.531	0.572
20	9.70	0.105	0.109	0.042	0.044	1.166	1.704	6.00	0.066	0.063	0.007	0.011	0.641	0.750
30	9.70	0.096	0.093	0.038	0.041	1.290	1.370	6.10	0.053	0.058	0.019	0.010	0.412	0.506

Table 2: Absorbances for WW

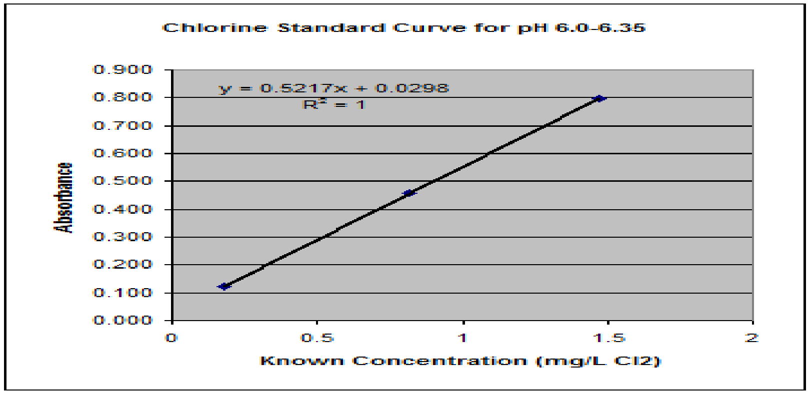
		Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm			Ferrate Absorbance Adjusted for wastewater at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Repl 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	9.70	0.091	0.090	0.048	0.042	1.920	2.202	6.10	0.046	0.043	-0.001	- 0.002	0.773	0.814
10	9.70	0.098	0.105	0.033	0.040	1.258	1.515	6.10	0.059	0.060	0.001	0.007	0.515	0.556
20	9.70	0.093	0.097	0.034	0.036	1.150	1.688	6.00	0.054	0.051	-0.001	0.003	0.625	0.734
30	9.70	0.084	0.081	0.030	0.033	1.274	1.354	6.10	0.041	0.046	0.011	0.002	0.396	0.490

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm							Ferrate Concentration (mg/L) at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Repl 2 Filt			pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 1 Conc (mg/L Cl_2)
0	9.70	9.46	9.35	4.99	4.36			6.10	4.78	4.47	-0.10	-0.21	1.431	1.510
10	9.70	10.18	10.91	3.43	4.16			6.10	6.13	6.23	0.10	0.73	0.934	1.013
20	9.70	9.66	10.08	3.53	3.74			6.00	5.61	5.30	-0.10	0.31	1.146	1.356
30	9.70	8.73	8.42	3.12	3.43			6.10	4.26	4.78	1.14	0.21	0.705	0.886

Date: 3/10/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Standard Formula (B) Ferrate in wastewater over 30 minutes



Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.016
Filtered Wastewater		0.010

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.012
Wastewater with DPD	0.029
Filtered Wastewater with DPD	0.046
Blank Gel	0.076
Std. 1	0.170
Std. 2	0.503
Std. 3	0.843

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentrat ion
Std. 1	0.124	0.18
Std. 2	0.457	0.82
Std. 3	0.797	1.47

The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

			Ferrate Absorbance based on DI water as zero at 510nm pH6				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Replicate 2 Absorbance
0		6.05	0.025	0.027	0.006	0.009	0.383	0.385
10		6.05	0.024	0.024	0.009	0.009	0.329	0.307
20		6.05	0.023	0.026	0.005	0.005	0.307	0.306
30		6.05	0.018	0.019	0.004	0.005	0.299	0.302

Table 2: Absorbance for WW

			Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0		6.05	0.009	0.011	-0.004	-0.001	0.337	0.339
10		6.05	0.008	0.008	-0.001	-0.001	0.283	0.261
20		6.05	0.007	0.010	-0.005	-0.005	0.261	0.260
30		6.05	0.002	0.003	-0.006	-0.005	0.253	0.256

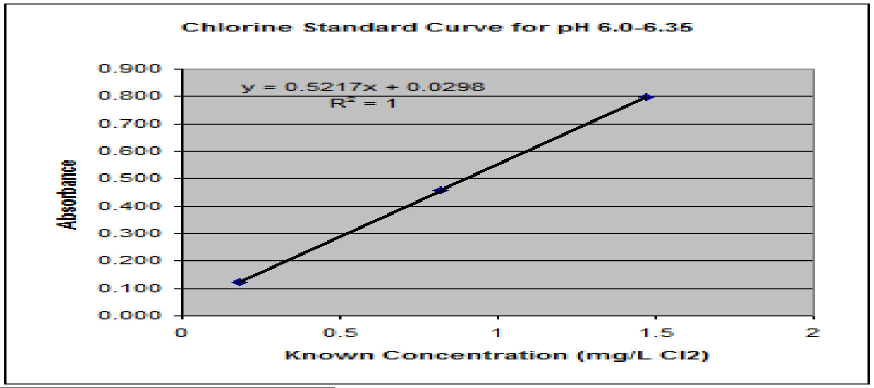
Table 3: Concentrations using Adjusted

Information

Time		Adjusted pH	Ferrate Concentration (mg/L) at 510nm: Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 1 Filtered	Replicate 2 Filtered	HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35: Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0		6.05	0.94	1.14	-0.42	-0.10	0.589	0.593
10		6.05	0.83	0.83	-0.10	-0.10	0.485	0.443
20		6.05	0.73	1.04	-0.52	-0.52	0.443	0.441
30		6.05	0.21	0.31	-0.62	-0.52	0.428	0.434

Date: 3/4/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Standard Formula (B) Ferrate in wastewater over 30 minutes



Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.016
Filtered Wastewater		0.010

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.012
	0.029

Wastewater with DPD	
Filtered Wastewater with DPD	0.046
Blank Gel	0.076
Std. 1	0.170
Std. 2	0.503
Std. 3	0.843

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.124	0.18
Std. 2	0.457	0.82
Std. 3	0.797	1.47

The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1:
Raw Data

			Ferrate Absorbance based on DI water as zero at 510nm pH6				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0		6.00	0.036	0.036	0.007	0.006	0.467	0.540
10		6.00	0.031	0.032	0.002	0.001	0.380	0.375
20		6.00	0.034	0.032	0.004	0.004	0.321	0.320
30		6.00	0.041	0.037	0.002	0.007	0.318	0.310

Table 2:
Absorbance
for WW

			Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Repl 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0		6.00	0.020	0.020	-0.003	-0.004	0.421	0.494
10		6.00	0.015	0.016	-0.008	-0.009	0.334	0.329
20		6.00	0.018	0.016	-0.006	-0.006	0.275	0.274
30		6.00	0.025	0.021	-0.008	-0.003	0.272	0.264

Table 3: Concentrations using Adjusted
Information

			Ferrate Concentration (mg/L) at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time		Adjusted pH	Rep 1 Unfilt	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0		6.00	2.08	2.08	-0.31	-0.42	0.750	0.890
10		6.00	1.56	1.66	-0.83	-0.94	0.583	0.574
20		6.00	1.87	1.66	-0.62	-0.62	0.470	0.468
30		6.00	2.60	2.18	-0.83	-0.31	0.464	0.449

Low Chlorine Formula Kinetics

Date: 2/20/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Formula A Ferrate in wastewater over 30 minutes

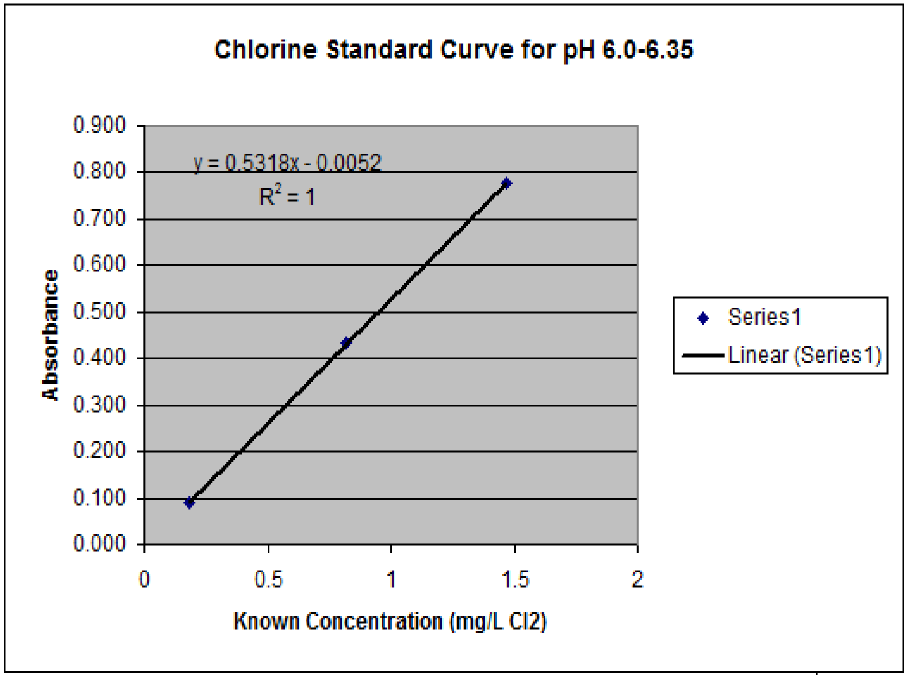
Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.019
Filtered Wastewater		0.014

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.008
Wastewater with DPD	0.072
Filtered Wastewater with DPD	0.046
Blank Gel	0.038
Std. 1	0.136
Std. 2	0.478
Std. 3	0.822

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.090	0.18
Std. 2	0.432	0.82
Std. 3	0.776	1.47



The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH			Ferrate Absorbance based on DI water as zero at 510nm, pH 6-6.35				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep2 Abs
0	9.86	0.120	0.120	0.038	0.036	1.006	1.058	5.46	0.080	0.082	0.014	0.015	0.174	0.138
10	9.96					0.772	0.815	6.31	0.094	0.094	0.011	0.014	0.250	0.235
20	9.90	0.131	0.131	0.022	0.022	0.592	0.536	6.11	0.097	0.094	0.011	0.014	0.164	0.149
30	9.90	0.070	0.069	0.019	0.019	0.454	0.450	6.32	0.064	0.061	0.015	0.015	0.188	0.172

Table 2: Absorbances for WW

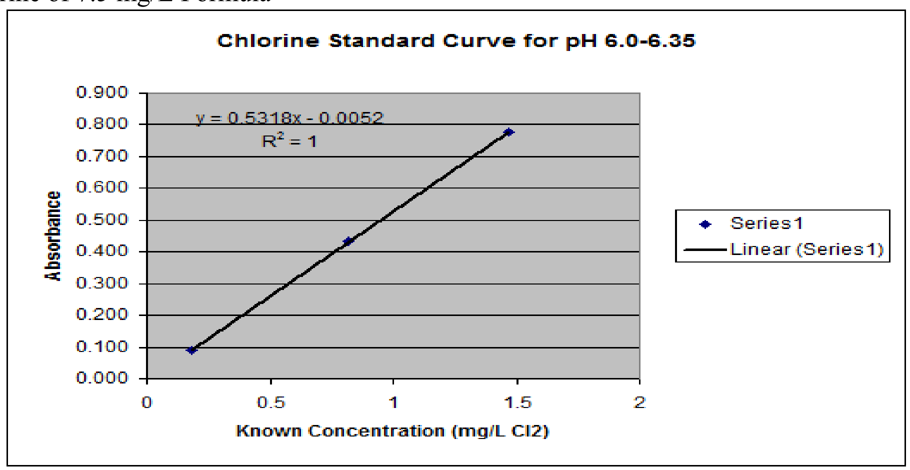
		Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm			Ferrate Absorbance Adjusted for wastewater at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	9.86	0.101	0.101	0.024	0.022	0.960	1.012	5.46	0.061	0.063	0.000	0.001	0.128	0.092
10	9.96					0.726	0.769	6.31	0.075	0.075	-0.003	0.000	0.204	0.189
20	9.90	0.112	0.112	0.008	0.008	0.546	0.490	6.11	0.078	0.075	-0.003	0.000	0.118	0.103
30	9.90	0.051	0.050	0.005	0.005	0.408	0.404	6.32	0.045	0.042	0.001	0.001	0.142	0.126

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm							Ferrate Concentration (mg/L) at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt			pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0	9.86	10.50	10.50	2.49	2.29			5.46	6.34	6.55	0.00	0.10	0.250	0.183
10	9.96							6.31	7.79	7.79	-0.31	0.00	0.393	0.365
20	9.90	11.64	11.64	0.83	0.83			6.11	8.11	7.79	-0.31	0.00	0.232	0.203
30	9.90	5.30	5.20	0.52	0.52			6.32	4.68	4.36	0.10	0.10	0.277	0.247

Date: 2/20/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Formula A Ferrate in wastewater over 30 minutes



Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.019
Filtered Wastewater		0.014

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.008

Wastewater with DPD	0.072
Filtered Wastewater with DPD	0.046
Blank Gel	0.038
Std. 1	0.136
Std. 2	0.478
Std. 3	0.822

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.090	0.18
Std. 2	0.432	0.82
Std. 3	0.776	1.47

Potassium Ferrate Standard Curve with DPD at 530 nm Equation: $y=0.0547x+0.1154$

The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH			Ferrate Absorbance based on DI water as zero at 510nm, pH 6-6.35				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	10.00	0.116	0.116	0.026	0.027	0.802	0.936	6.23	0.079	0.079	0.008	0.009	0.192	0.204
10	10.00	0.097	0.106	0.024	0.020	0.613	0.588	6.08	0.102		0.019	0.011	0.156	0.153
20	9.97	0.105	0.114	0.015	0.015	0.414	0.419	6.26	0.095	0.085	0.009	0.009	0.157	0.163
30	9.96	0.055	0.064	0.013	0.013	0.315	0.321	6.26	0.050	0.051	0.007	0.007	0.175	0.166

Table 2:
Absorbance for
WW

		Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm			Ferrate Absorbance Adjusted for wastewater at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	10.00	0.097	0.097	0.012	0.013	0.756	0.890	6.23	0.060	0.060	-0.006	-0.005	0.146	0.158
10	10.00	0.078	0.087	0.010	0.006	0.567	0.542	6.08	0.083		0.005	-0.003	0.110	0.107
20	9.97	0.086	0.095	0.001	0.001	0.368	0.373	6.26	0.076	0.066	-0.005	-0.005	0.111	0.117
30	9.96	0.036	0.045	-0.001	-0.001	0.269	0.275	6.26	0.031	0.032	-0.007	-0.007	0.129	0.120

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm							Ferrate Concentration (mg/L) at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Fil	Rep 2 Filt			pH	Rep 1 Unf	Rep 2 UnFd	Rep1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0	10.00	10.08	10.08	1.25	1.35			6.23	6.23	6.23	-0.62	-0.52	0.284	0.307
10	10.00	8.11	9.04	1.04	0.62			6.08	8.62		0.52	-0.31	0.217	0.211
20	9.97	8.94	9.87	0.10	0.10			6.26	7.90	6.86	-0.52	-0.52	0.219	0.230
30	9.96	3.74	4.68	-0.10	-0.10			6.26	3.22	3.33	-0.73	-0.73	0.252	0.235

Date: 2/28/2008

Objective: Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Formula A Ferrate in wastewater over 30 minutes

Spectrasuite

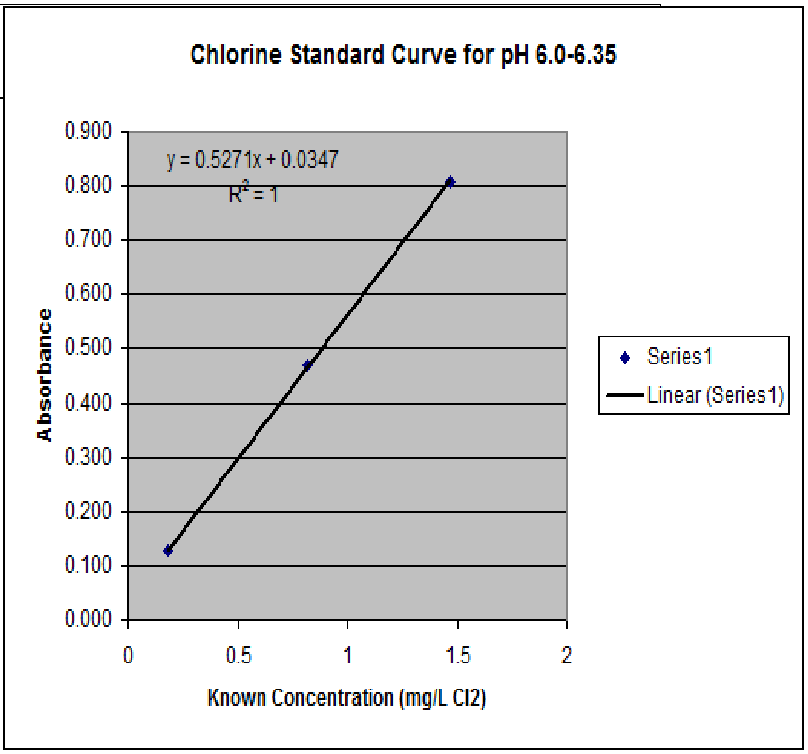
Zero-DI water		Absorbance
Wastewater		0.019
Filtered Wastewater		0.007

Hach Spectrophotometer Setup

Zero on Di water in circular cell	
Di in Square sample cell	-0.048
Di with DPD in square sample cell	-0.039
Wastewater with DPD in SSC	0.014
Filtered Wastewater with DPD in SSC	0.007
Blank Gel	0.041
Std. 1	0.136
Std. 2	0.475
Std. 3	0.816
Note: SSC=square sample cell	

Chlorine Standard Curve with respect to filtered wastewater with DPD

Sample	Abs	Known Concentration
Std. 1	0.129	0.18
Std. 2	0.468	0.82
Std. 3	0.809	1.47



The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

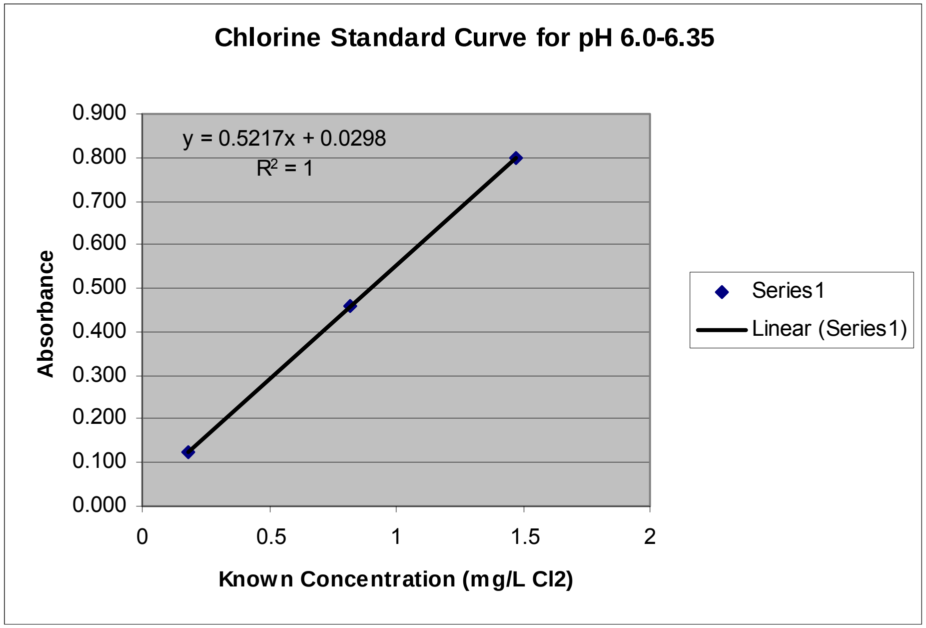
		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH			Ferrate Absorbance based on DI water as zero at 510nm, pH 6-6.35				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep2 Filt	Rep 1 Abs	Rep 2 Abs
0	10.00	0.140	0.144	0.048	0.041	1.305	1.250	6.06	0.077	0.076	0.002	-0.001	0.237	0.236
10	10.16	0.123	0.111	0.033	0.029	0.962	1.147	5.90	0.078	0.078	0.001	-0.002	0.192	0.299
20	10.17	0.114	0.112	0.029	0.021	0.935	0.996	6.30	0.075	0.079	0.003	0.004	0.247	0.226
30	10.13	0.060	0.062	0.021	0.022	0.723	0.818	6.18	0.067	0.056	0.005	0.006	0.243	0.188

Table 2: Absorbance for WW

		Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm			Ferrate Absorbance Adjusted for wastewater at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0	10.00	0.121	0.125	0.041	0.034	1.298	1.243	6.06	0.058	0.057	-0.005	-0.008	0.230	0.229
10	10.16	0.104	0.092	0.026	0.022	0.955	1.140	5.90	0.059	0.059	-0.006	-0.009	0.185	0.292
20	10.17	0.095	0.093	0.022	0.014	0.928	0.989	6.30	0.056	0.060	-0.004	-0.003	0.240	0.219
30	10.13	0.041	0.043	0.014	0.015	0.716	0.811	6.18	0.048	0.037	-0.002	-0.001	0.236	0.181

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm							Ferrate Concentration (mg/L) at 510nm, ph 6.0-6.35				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt			pH	Rep 1 Unf	Repl 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0	10.00	12.57	12.99	4.26	3.53			6.06	6.03	5.92	-0.52	-0.83	0.502	0.500
10	10.16	10.81	9.56	2.70	2.29			5.90	6.13		-0.62	-0.94	0.417	0.620
20	10.17	9.87	9.66	2.29	1.45			6.30	5.82	6.23	-0.42	-0.31	0.521	0.481
30	10.13	4.26	4.47	1.45	1.56			6.18	4.99	3.84	-0.21	-0.10	0.514	0.409



Date:	3/10/2008
Objective:	Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Formula A Ferrate in wastewater over 30 minutes at pH 6

Spectrasuite

Zero-DI water			Absorbance
Wastewater			0.016
Filtered Wastewater			0.010

Hach Spectrophotometer Setup

Zero on Di water in square cell	
Di with DPD in square sample cell	0.012
Wastewater with DPD in SSC	0.029
Filtered Wastewater with DPD in SSC	0.046
Blank Gel	0.076
Std. 1	0.170
Std. 2	0.503
Std. 3	0.843
Note: SSC=square sample cell	

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.124	0.18
Std. 2	0.457	0.82
Std. 3	0.797	1.47

The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

			Ferrate Absorbance based on DI water as zero at 510nm pH6				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Repl 2 Filt	Rep 1 Abs	Replicate 2 Absorbance
0		6.07	0.065	0.063	0.005	0.006	0.246	0.245
10		6.07	0.059	0.062	0.008	0.010	0.206	0.205
20		6.07	0.060	0.063	0.007	0.007	0.198	0.192
30		6.07	0.058	0.059	0.006	0.009	0.166	0.179

Table 2:
Absorbance for
WW

			Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time		Adjusted pH	Rep 1 Unf	Replicate 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs
0		6.07	0.049	0.047	-0.005	-0.004	0.200	0.199
10		6.07	0.043	0.046	-0.002	0.000	0.160	0.159
20		6.07	0.044	0.047	-0.003	-0.003	0.152	0.146
30		6.07	0.042	0.043	-0.004	-0.001	0.120	0.133

Table 3: Concentrations using Adjusted
Information

			Ferrate Concentration (mg/L) at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0		6.07	5.09	4.88	-0.52	-0.42	0.326	0.324
10		6.07	4.47	4.78	-0.21	0.00	0.250	0.248
20		6.07	4.57	4.88	-0.31	-0.31	0.234	0.223
30		6.07	4.36	4.47	-0.42	-0.10	0.173	0.198

Date:	3/10/2008
Objective:	Measure ferrate, total oxidant, and total chlorine of 7.5 mg/L Formula A Ferrate in wastewater over 30 minutes at pH 6

Spectrasuite

Zero-DI water			Absorbance
Wastewater			0.016
Filtered Wastewater			0.010

Hach Spectrophotometer Setup

Zero on Di water in square cell	
Di with DPD in square sample cell	0.012
Wastewater with DPD in SSC	0.029
Filtered Wastewater with DPD in SSC	0.046
Blank Gel	0.076
Std. 1	0.170
Std. 2	0.503
Std. 3	0.843
Note: SSC=square sample cell	

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.124	0.18
Std. 2	0.457	0.82
Std. 3	0.797	1.47

The mixture was mixed at 300 rpm for the first two minutes and then 75 rpm for 28 minutes

Table 1: Raw Data

Time		Adjusted pH	Ferrate Absorbance based on DI water as zero at 510nm pH6 Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35 Rep 1 Abs	Rep 2 Abs
0		6.00	0.090	0.080	0.004	0.003	0.221	0.209
10		6.00	0.083	0.050	-0.007	-0.006	0.195	0.222
20		6.00	0.071	0.067	-0.005	-0.007	0.190	0.217
30		6.00	0.093	0.094	0.005	0.002	0.256	0.273

Table 2: Absorbance for WW

Time		Adjusted pH	Ferrate Absorbance Adjusted for wastewater at 510nm Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35 Rep 1 Abs	Rep 2 Abs
0		6.00	0.074	0.064	-0.006	-0.007	0.175	0.163
10		6.00	0.067	0.034	-0.017	-0.016	0.149	0.176
20		6.00	0.055	0.051	-0.015	-0.017	0.144	0.171
30		6.00	0.077	0.078	-0.005	-0.008	0.210	0.227

Table 3: Concentrations using Adjusted Information

			Ferrate Concentration (mg/L) at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Time		Adjusted pH	Rep 1 Unf	Rep 2 UnF	Rep1 Filt	Rep 2 Filt	Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
0		6.00	7.69	6.65	-0.62	-0.73	0.278	0.255
10		6.00	6.96	3.53	-1.77	-1.66	0.228	0.280
20		6.00	5.72	5.30	-1.56	-1.77	0.219	0.271
30		6.00	8.00	8.11	-0.52	-0.83	0.345	0.378

C-3 Wastewater Data

Enterococcus Bacteria Disinfection Calculations for Standard Formula in Wastewater

Enterococcus Bacteria For Standard Formula							
Conc.(mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	Log Removal
	0	2419.6					
	0	2419.6					
	2	1180					
	2	2300					
	4	10000					
0	4	10000	4719.87	4116.52	8836.38	603.35	N/A
	0	533.5					
	2	100					
	2	400					
	4	10000					
	4	10000					
	0	533.5					
	0	2419.6					
	2	302					
	2	102					
	4	10000					
2	4	10000	4035.51	4770.29	8805.80	-734.78	0.068031
	0	10.4					
	2	100					
	2	100					
	0	16.4					
	0	14.1					
	2	100					
4	2	200	77.27	69.26	146.53	8.01	1.785911
	0	18.3					
	0	12.1					
	0	18.9					
	0	16					
	0	113					
	0	190.4					
7.5	0	285.1	16.33	3.08	19.41	13.24	2.461077

Enterococcus Bacteria Disinfection Calculations for Low Chlorine Formula in Wastewater

Enterococcus Bacteria For Low Chlorine Formula							
Conc.(mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	Log Removal
	0	261.3					
	0	2419.6					
	2	2750					
	2	2030					
	3	2000					
0	3	5200	2443.48	1601.40	4044.89	842.08	N/A
	0	1299.7					
	0	1732.9					
	2	1340					
	2	1340					
	0	1986.3					
	0	1986.3					
	2	3130					
2	2	1600	1801.90	604.30	2406.20	1197.60	0.132279
	0	461.1					
	0	816.4					
	1	591					
	1	336					
	0	1119.9					
	0	613.1					
	1	345					
4	1	345	578.44	275.86	854.30	302.58	0.625753
	0	156.5					
	0	113					
	0	190.4					
7.5	0	285.1	82.60	87.92	170.52	-5.32	1.471029

E. Coli Disinfection Calculations for Standard Formula in Wastewater

E. Coli Bacteria For Standard Formula

Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	log removal
	0	866.4					
	0	1299.7					
	2	1100					
	2	960					
	4	10000					
0-B	4	10000	4037.68	4620.70	8658.38	-583.01	N/A
	0	193.5					
	2	520					
	2	740					
	4	10000					
	4	10000					
	0	56					
	0	57.6					
	2	100					
	2	630					
	4	10000					
2-B	4	10000	3845.19	4884.96	8730.15	-1039.77	0.02
	0	1					
	2	100					
	2	100					
	0	2					
	0	1					
	2	100					
4-B	2	100	57.71	52.74	110.45	4.97	1.84
	0	1					
	0	1					
	0	1					
	0	1					
	0	1					
	0	1					
7.5-B	0	1	1.00	0.00	1.00	1.00	3.61

E. Coli Disinfection Calculations for Low Chlorine Formula in Wastewater

E. Coli Bacteria For Low Chlorine Formula

Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	log removal
	0	2419.6					
	0	2419.6					
	2	2460					
	2	3180					
	3	6300					
0-A	3	4100	3479.87	1530.76	5010.62	1949.11	N/A
	0	2419.6					
	0	2419.6					
	2	1090					
	2	940					
	0	2419.6					
	0	2419.6					
	2	198630					
2-A	2	241960	56537.30	101736.55	158273.85	-45199.25	-1.21
	0	1732.9					
	0	1413.6					
	1	505					
	1	687					
	0	1119.9					
	0	1986.3					
	1	792					
4-A	1	668	1113.09	546.36	1659.44	566.73	0.50
	0	1					
	0	1					
	0	1					
7.5-A	0	1	1.00	0.00	1.00	1.00	3.54

Total Coliform Disinfection Calculations for Standard Formula in Wastewater

Total Coliform Bacteria For Standard Formula

Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	Log removal
	0	2419.6					
	0	2419.6					
	2	198630					
	2	2419630					
	4	305000					
0-B	4	309000	539516.53	931247.81	1470764.34	-391731.27	N/A
	0	2419.6					
	2	22470					
	2	30760					
	4	2419.6					
	4	2419.6					
	0	2419.6					
	0	2419.6					
	2	17890					
	2	23820					
	4	10000					
2-B	4	20000	12458.00	10773.00	23231.00	1685.00	1.64
	0	9.4					
	2	200					
	2	310					
	0	55.2					
	0	59.2					
	2	100					
4-B	2	310	149.11	124.63	273.74	24.49	3.56
	0	488.4					
	0	5.2					
	0	18.7					
	0	13.5					
	0	27.5					
	0	26.5					
7.5-B	0	12.2	131.45	238.03	369.48	-106.58	3.61

Total Coliform Disinfection Calculations for Low Chlorine Formula in Wastewater

Total Coliform Bacteria For Low Chlorine Formula

Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	Log removal
	0	2419.6					
	0	2419.6					
	2	2419.6					
	2	198630					
	3	235900					
0-A	3	155300	99514.80	109379.31	208894.11	-9864.51	N/A
	0	2419.6					
	0	2419.6					
	2	241960					
	2	173290					
	0	2419.6					
	0	2419.6					
	2	198630					
2-A	2	241960	108189.80	115236.24	223426.04	-7046.44	-0.04
	0	2419.6					
	0	2419.6					
	1	15531					
	1	12997					
	0	2419.6					
	0	2419.6					
	1	19863					
4-A	1	19863	9741.55	8136.75	17878.30	1604.80	1.01
	0	24.6					
	0	27.5					
	0	26.5					
7.5-A	0	12.2	22.70	7.10	29.80	15.60	3.64

Heterotrophic Bacteria Disinfection Calculations for Standard Formula in Wastewater

Conc. (mg/l)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for dilution	Mean	Standard Deviation	Mean+ stdev	Mean- stdev	Log removal
	1	308	3080					
	1	256	2560					
0-B	1	228	2280	2640.00	405.96	3045.96	2234.04	N/A
	1	188	1880					
	1	152	1520					
	1	144	1440					
	2	148	14800					
	2	56	5600					
	1	160	1600					
	1	192	1920					
	1	132	1320					
	2	53	5300					
	2	63	6300					
2-B	2	59	5900	4325.45	4038.47	8363.92	286.99	-0.21
	1	160	1600					
	1	148	1480					
	1	168	1680					
	2	40	4000					
	2	75	7500					
	2	42	4200					
	1	116	1160					
	1	156	1560					
4-B	1	136	1360	2726.67	2126.59	4853.26	600.07	-0.01
	1	120	1200					
	1	59	590					
	1	84	840					
	1	72	720					
	1	69	690					
7.5-B	1	89	890	821.67	214.24	1035.90	607.43	0.51

Heterotrophic Bacteria Disinfection Calculations for Low Chlorine Formula in Wastewater

Conc. (mg/l)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for dilution	Mean	Standard Deviation	Mean+ stdev	Mean- stdev	Log removal
	1	224	2240					
	1	180	1800					
0-A	1	220	2200	2080.00	243.31	2323.31	1836.69	N/A
	1	196	1960					
	1	196	1960					
	1	224	2240					
	2	94	9400					
	2	192	19200					
	2	91	9100					
	1	168	1680					
	1	164	1640					
	1	216	2160					
	2	112	11200					
	2	140	14000					
2-A	2	115	11500	7170.00	6026.24	13196.2 4	1143.76	-0.54
	1	152	1520					
	1	192	1920					
	1	164	1640					
	2	92	9200					
	2	63	6300					
	2	62	6200					
	1	136	1360					
	1	172	1720					
	1	188	1880					
	2	71	7100					
	2	100	10000					
4-A	2	77	7700	4711.67	3345.30	8056.96	1366.37	-0.36
	1	128	1280					
	1	196	1960					
7.5-A	1	104	1040	1426.67	477.21	1903.88	949.45	0.16

Standard Formula Data

Enterococcus Bacteria Disinfection Data for Standard Formula in Wastewater

Objective:	Quantify Enterococcus at varying doses of Fe (VI) in wastewater at 30 min contact time					
Date of Experiment:	4/4/2008					
Date read:	4/5/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	49	48	>2419.6	>2419.6	>24.196
0	0	49	48	>2419.6	>2419.6	>24.196
0	2	7	4	11.8	1180	11.8
0	2	13	7	23	2300	23
0	4	0	0	<1	<10000	<100
0	4	1	0	1	10000	100
2	0	46	48	533.5	533.5	5.335
2	2	1	0	1	100	1
2	2	0	4	4	400	4
2	4	0	0	<1	<10000	<100
2	4	0	0	<1	<10000	<100
2	0	46	48	533.5	533.5	5.335
2	0	49	48	>2419.6	>2419.6	>24.196
2	2	2	1	3	302	3.02
2	2	1	1	1	102	1.02
2	4	0	0	<1	<10000	<100
2	4	0	0	<1	<10000	<100
4	0	4	6	10.4	10.4	0.104
4	2	0	0	<1	<100	<100
4	2	0	0	<1	<100	<100
4	0	9	6	16.4	16.4	0.164
4	0	8	5	14.1	14.1	0.141
4	2	0	0	<1	<100	<1
4	2	1	0	2	200	2
7.5	0	13	3	18.3	18.3	0.183
7.5	0	10	1	12.1	12.1	0.121
7.5	0	16	0	18.9	18.9	0.189
7.5	0	13	1	16	16	0.16
Controls						
Enterococcus	3	49	48	>2419.6	>2419600	>24196

E. Coli Disinfection Data for Standard Formula in Wastewater

Objective:	Quantify E. coli at varying doses of Fe (VI) in wastewater at 30 min contact time					
Date of Experiment:	4/4/2008					
Date read:	4/5/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	49	36	866.4	866.4	8.664
0	0	49	42	1299.7	1299.7	12.997
0	2	10	0	11	1100	11
0	2	7	2	9.6	960	9.6
0	4	0	0	<1	<10000	<100
0	4	0	0	<1	<10000	<100
2	0	48	12	193.5	193.5	1.935
2	2	5	0	5.2	520	5.2
2	2	6	1	7.4	740	7.4
2	4	0	0	<1	<10000	<100
2	4	0	0	<1	<10000	<100
2	0	27	12	56	56	0.56
2	0	27	13	57.6	57.6	0.576
2	2	1	0	1	100	1
2	2	5	1	6.3	630	6.3
2	4	0	0	<1	<10000	<100
2	4	0	0	<1	<10000	<100
4	0	0	0	<1	<1	<0.01
4	2	0	0	<1	<100	<1
4	2	0	0	<1	<100	<1
4	0	1	1	2	2	0.02
4	0	1	0	1	1	0.01
4	2	0	0	<1	<100	<1
4	2	0	0	<1	<100	<1
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	1	0	1	1	0.01

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	2	49	48	>2419.7	>241960	>2419.7
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Total Coliform Disinfection Data for Standard Formula in Wastewater

Objective:	Quantify Total Coliform at varying doses of Fe (VI) in wastewater at 30 min contact time					
Date of Experiment:	4/4/2008					
Date read:	4/5/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	49	48	>2419.6	>2419.6	>2419.6
0	0	49	48	>2419.6	>2419.6	>2419.6
0	2	49	46	1986.3	198630	1986.3
0	2	49	47	2419.6	241960	2419.6
0	4	21	3	30.5	305000	3050
0	4	22	2	30.9	309000	3090
2	0	49	48	>2419.6	>2419.6	>2419.6
2	2	49	12	224.7	22470	224.7
2	2	49	18	307.6	30760	307.6
2	4	0	0	>2419.6	>2419.6	>2419.6
2	4	2	0	>2419.6	>2419.6	>2419.6
2	0	49	48	>2419.6	>2419.6	>2419.6
2	0	49	48	>2419.6	>2419.6	>2419.6
2	2	48	10	178.9	17890	178.9
2	2	48	17	238.2	23820	238.2
2	4	1	0	1	10000	100
2	4	2	0	2	20000	200
4	0	5	4	9.4	9.4	0.094
4	2	2	0	2	200	2
4	2	3	0	3.1	310	3.1
4	0	28	10	55.2	55.2	0.552
4	0	27	14	59.2	59.2	0.592
4	2	0	0	<1	<100	<1
4	2	3	0	3.1	310	3.1
7.5	0	49	26	488.4	488.4	4.884
7.5	0	5	0	5.2	5.2	0.052
7.5	0	15	1	18.7	18.7	0.187
7.5	0	12	0	13.5	13.5	0.135

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	2	49	48	>2419.7	>241960	>2419.7
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Heterotrophic Bacteria Disinfection Data for Standard Formula in Wastewater

Conc.(mg/l)	Dilution, (10^n)	Plated Dilution, (10^n)	Colony Forming Units (CFU) Plate 1	Plate 2	Plate 3	Avg CFU	Avg CFU/mL
0	0	1	308	256	228	264	2640.00
0	1	2	6	5	2	4	433.33
0	2	3	0	1	1	1	666.67
2 Dup 1	0	1	188	152	144	161	1613.33
2 Dup 1	1	2	148	600	56	268	26800.00
2 Dup 2	0	1	160	192	132	161	1613.33
2 Dup 2	1	2	53	63	59	58	5833.33
4 Dup 1	0	1	160	148	168	159	1586.67
4 Dup 1	1	2	40	75	42	52	5233.33
4 Dup 2	0	1	116	156	136	136	1360.00
4 Dup 2	1	2	27	29	19	25	2500.00
7.5 Dup 1	0	1	120	59	84	88	876.67
7.5 Dup 1	1	2	10	7	8	8	833.33
7.5 Dup 2	0	1	72	69	89	77	766.67
7.5 Dup 2	1	2	19	18	17	18	1800.00
Controls							
Open			0	0			
Closed			0	0			
Dilution Buffer			0	0			

DOC Standard Curve Data for Standard Formula in Wastewater

Objective: Measure DOC of varying doses of ferrate in wastewater at 30 minute contact time.

Known Concentration of C (mg/L)	Counts	Concentration from Instrument (mg/L DOC)
0	132542	0.1381
0	126135	0.1314
0	112507	0.1172
0	117226	0.1221
0	111384	0.116
0	105843	0.1103
0.5	658352	0.6858
0.5	638479	0.6651
0.5	642028	0.6688
1	1142327	1.1899
1	1156600	1.2048
1	1139816	1.1873
2	1979938	2.0624
2	1956172	2.0377
2	1962524	2.0443
5	4472317	4.6587
5	4430112	4.6147
5	4403964	4.5875
10	9103535	9.4828
10	9072484	9.4505
10	9104790	9.4842
20	17909599	18.6558
20	18214091	18.973
20	18057047	18.8094
0	191162	0.1991
0	126490	0.1318
0	123999	0.1292

DOC Data for Standard Formula in Wastewater

Sample	Counts	Concentration from DOC Instrument (mg/L DOC)	Concentration from Standard Curve (mg/L DOC)
Wastewater Replicate 1	10706437	11.1525	11.81
Wastewater Replicate 1	10789578	11.2391	11.90
Wastewater Replicate 1	10789323	11.2389	11.90
Wastewater Replicate 2	10911727	11.3664	12.04
Wastewater Replicate 2	10863951	11.3166	11.99
Wastewater Replicate 2	10896778	11.3508	12.02
2 mg/L Fe (VI) in WW Dup 1 Rep 1	10821840	11.2727	11.94
2 mg/L Fe (VI) in WW Dup 1 Rep 1	10739003	11.1865	11.85
2 mg/L Fe (VI) in WW Dup 1 Rep 1	10813658	11.2642	11.93
2 mg/L Fe (VI) in WW Dup 1 Rep 2	10835353	11.2868	11.96
2 mg/L Fe (VI) in WW Dup 1 Rep 2	10760152	11.2085	11.87
2 mg/L Fe (VI) in WW Dup 1 Rep 2	10725793	11.1727	11.83
2 mg/L Fe (VI) in WW Dup 2 Rep 1	10762408	11.2108	11.87
2 mg/L Fe (VI) in WW Dup 2 Rep 1	10785491	11.2349	11.90
2 mg/L Fe (VI) in WW Dup 2 Rep 1	10886360	11.34	12.01
2 mg/L Fe (VI) in WW Dup 2 Rep 2	10936050	11.3917	12.07
2 mg/L Fe (VI) in WW Dup 2 Rep 2	10853775	11.306	11.98
2 mg/L Fe (VI) in WW Dup 2 Rep 2	10803414	11.2536	11.92
4 mg/L Fe (VI) in WW Dup 1 Rep 1	10598829	11.0404	11.69
4 mg/L Fe (VI) in WW Dup 1 Rep 1	10626972	11.0698	11.72
4 mg/L Fe (VI) in WW Dup 1 Rep 1	10641968	11.0854	11.74
4 mg/L Fe (VI) in WW Dup 1 Rep 2	10646886	11.0905	11.74
4 mg/L Fe (VI) in WW Dup 1 Rep 2	10675741	11.1206	11.78
4 mg/L Fe (VI) in WW Dup 1 Rep 2	10637531	11.0808	11.73
4 mg/L Fe (VI) in WW Dup 2 Rep 1	10499973	10.9375	11.58
4 mg/L Fe (VI) in WW Dup 2 Rep 1	10510681	10.9486	11.59
4 mg/L Fe (VI) in WW Dup 2 Rep 1	10375583	10.8079	11.44
4 mg/L Fe (VI) in WW Dup 2 Rep 2	10466464	10.9026	11.54
4 mg/L Fe (VI) in WW Dup 2 Rep 2	10528147	10.9668	11.61
4 mg/L Fe (VI) in WW Dup 2 Rep 2	10490595	10.9277	11.57
7.5 mg/L Fe (VI) in WW Dup 1 Rep 1	10426037	10.8605	11.50
7.5 mg/L Fe (VI) in WW Dup 1 Rep 1	10380097	10.8126	11.45
7.5 mg/L Fe (VI) in WW Dup 1 Rep 1	10337635	10.7684	11.40
7.5 mg/L Fe (VI) in WW Dup 1 Rep 2	10507561	10.9454	11.59
7.5 mg/L Fe (VI) in WW Dup 1 Rep 2	10339264	10.7701	11.40
7.5 mg/L Fe (VI) in WW Dup 1 Rep 2	10456679	10.8924	11.53
7.5 mg/L Fe (VI) in WW Dup 2 Rep 1	10365429	10.7973	11.43
7.5 mg/L Fe (VI) in WW Dup 2 Rep 1	10271247	10.6992	11.32
7.5 mg/L Fe (VI) in WW Dup 2 Rep 1	10280951	10.7093	11.34
7.5 mg/L Fe (VI) in WW Dup 2 Rep 2	10223194	10.6492	11.27
7.5 mg/L Fe (VI) in WW Dup 2 Rep 2	10158686	10.582	11.20
7.5 mg/L Fe (VI) in WW Dup 2 Rep 2	10252590	10.6798	11.30

Date: 4/3/2008

Objective: Measure ferrate, total oxidant, and total chlorine of Formula A Ferrate in wastewater at 30 minutes

Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.020
Filtered Wastewater		0.013

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.011
Wastewater with DPD	0.044
Filtered Wastewater with DPD	0.052
Blank Gel	0.079
Std. 1	0.180
Std. 2	0.519
Std. 3	0.868

Chlorine Standard Curve with respect to filtered wastewater with DPD

Sample	Abs	Known Concentration
Std. 1	0.128	0.18
Std. 2	0.467	0.82
Std. 3	0.816	1.47

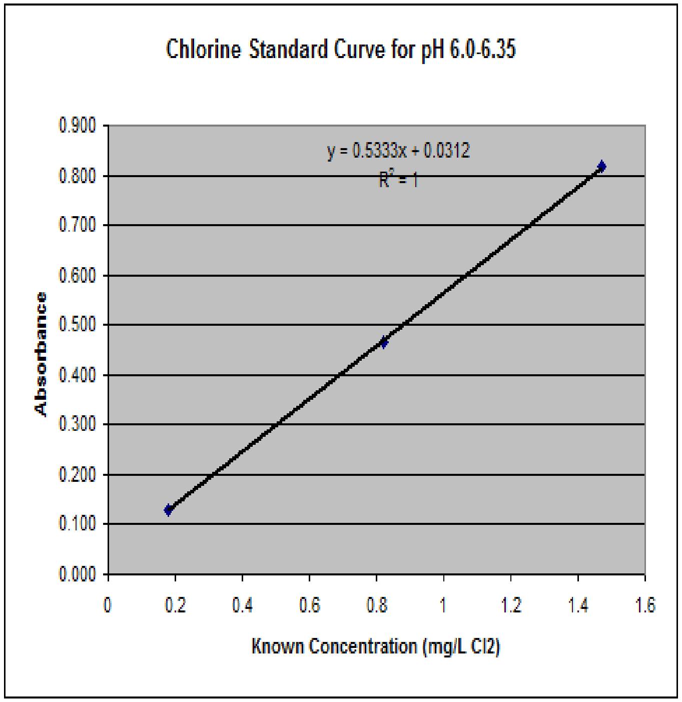


Table 1: Raw Data

		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH		HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Ferrate Conc (mg/L) in WW	pH	Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	Rep 1 Abs	Rep 2 Abs
2 Dup 1	8.60	0.018	0.022	0.009	0.012	0.240	0.246	0.109	0.126
2 Dup 2	8.52	0.028	0.023	0.015	0.009	0.283	0.290	0.192	0.152
4 Dup 1	8.91	0.026	0.025	0.008	0.013	0.618	0.637	0.558	0.598
4 Dup 2	8.90	0.029	0.026	0.008	0.018	0.554	0.545	0.544	0.537
7.5 Dup 1	9.22	0.046	0.036	0.006	0.011	0.800	0.803	0.621	0.694
7.5 Dup 2	9.25	0.031	0.027	0.009	0.010	0.879	0.864	0.714	0.711

Table 2: Absorbances for WW

		Ferrate Absorbance Adjusted for wastewater at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm		HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Ferrate Concentration (mg/L) in WW	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	Rep 1 Abs	Rep 2 Abs	Rep 1 Abs	Rep 2 Abs
2 Dup 1	8.60	-0.002	0.002	-0.004	-0.001	0.188	0.194	0.057	0.074
2 Dup 2	8.52	0.008	0.003	0.002	-0.004	0.231	0.238	0.140	0.100
4 Dup 1	8.91	0.006	0.005	-0.005	0.000	0.566	0.585	0.506	0.546
4 Dup 2	8.90	0.009	0.006	-0.005	0.005	0.502	0.493	0.492	0.485
7.5 Dup 1	9.22	0.026	0.016	-0.007	-0.002	0.748	0.751	0.569	0.642
7.5 Dup 2	9.25	0.011	0.007	-0.004	-0.003	0.827	0.812	0.662	0.659

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm				HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Ferrate Concentration (mg/L) in WW	pH	Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 1 Filtered	Replicate 2 Filtered	Replicate 1 Concentration (mg/L Cl_2)	Replicate 2 Concentration (mg/L Cl_2)
2 Dup 1	8.60	-0.21	0.21	-0.42	-0.10	0.048	0.080
2 Dup 2	8.52	0.83	0.31	0.21	-0.42	0.204	0.129
4 Dup 1	8.91	0.62	0.52	-0.52	0.00	0.890	0.965
4 Dup 2	8.90	0.94	0.62	-0.52	0.52	0.864	0.851
7.5 Dup 1	9.22	2.70	1.66	-0.73	-0.21	1.008	1.145
7.5 Dup 2	9.25	1.14	0.73	-0.42	-0.31	1.183	1.177

Low Chlorine Formula Data

Date: 4/2/2008

Objective: Measure ferrate, total oxidant, and total chlorine of Formula A Ferrate in wastewater at 30 minutes

Spectrasuite

Zero-DI water		Absorbance
Wastewater		0.016
Filtered Wastewater		0.010

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.009
Wastewater with DPD	0.042
Filtered Wastewater with DPD	0.059
Blank Gel	0.076
Std. 1	0.171
Std. 2	0.508
Std. 3	0.852

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.112	0.18
Std. 2	0.449	0.82
Std. 3	0.793	1.47

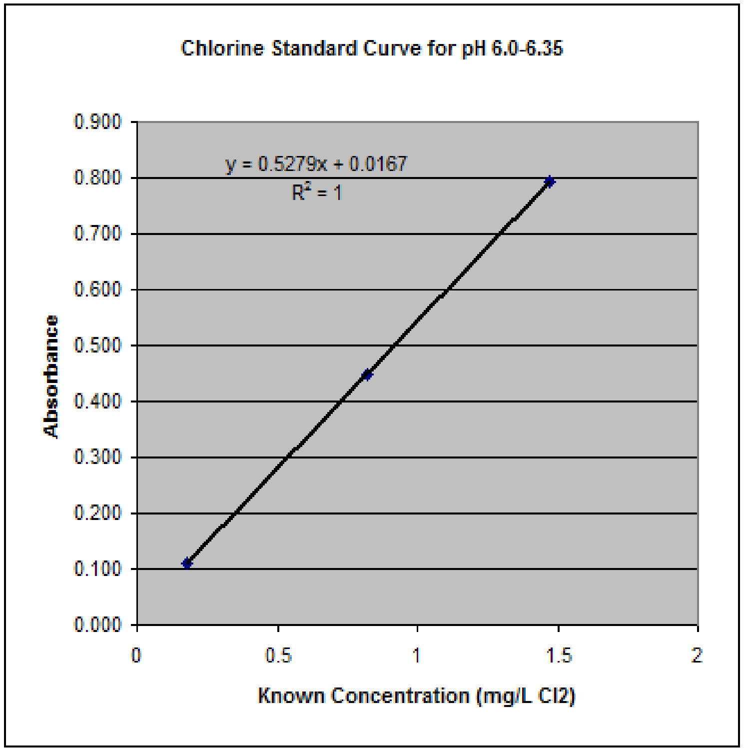


Table 1: Raw Data

Ferrate Concentration (mg/L) in WW	pH	Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH: Rep 1 Unf	Rep 2 UnF	Rep 2 Filt	Rep 2 Filt	HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH: Rep 1 Abs	Rep 2 Abs	HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35: Repl 1 Abs	Rep 2 Abs
2 Dup 1	8.81	0.037	0.030	0.003	0.005	0.108	0.099	0.038	0.061
2 Dup 2	8.72	0.024	0.024	0.002	0.004	0.116	0.102	0.040	0.056
4 Dup 1	9.05	0.037	0.055	0.000	-0.003	0.218	0.232	0.106	0.085
4 Dup 2	9.02	0.056	0.040	0.004	0.003	0.201	0.205	0.103	0.084
7.5 Dup 1	9.60	0.070	0.076	0.000	-0.002	0.453	0.425	0.214	0.216
7.5 Dup 2	9.58	0.039	0.065	0.002	-0.004	0.468	0.441	0.157	0.133

Table 2: Absorbances for WW

Ferrate Concentration (mg/L) in WW	pH	Ferrate Absorbance Adjusted for wastewater at 510nm: Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep 2 Filt	HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm: Rep 1 Abs	Rep 2 Abs	HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35: Rep 1 Abs	Rep 2 Abs
2 Dup 1	8.81	0.021	0.014	-0.007	-0.005	0.049	0.040	-0.021	0.002
2 Dup 2	8.72	0.008	0.008	-0.008	-0.006	0.057	0.043	-0.019	-0.003
4 Dup 1	9.05	0.021	0.039	-0.010	-0.013	0.159	0.173	0.047	0.026
4 Dup 2	9.02	0.040	0.024	-0.006	-0.007	0.142	0.146	0.044	0.025
7.5 Dup 1	9.60	0.054	0.060	-0.010	-0.012	0.394	0.366	0.155	0.157
7.5 Dup 2	9.58	0.023	0.049	-0.008	-0.014	0.409	0.382	0.098	0.074

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm						HACH DPD Total Chlorine with respect to Filtered Wastewater with DPD at 530 nm, ph 6.0-6.35	
Ferrate Concentration (mg/L) in WW	pH	Rep 1 Unf	Rep 2 UnF	Rep 1 Filt	Rep2 Filt			Rep 1 Conc (mg/L Cl_2)	Rep 2 Conc (mg/L Cl_2)
2 Dup 1	8.81	2.18	1.45	-0.73	-0.52			-0.071	-0.028
2 Dup 2	8.72	0.83	0.83	-0.83	-0.62			-0.068	-0.037
4 Dup 1	9.05	2.18	4.05	-1.04	-1.35			0.057	0.018
4 Dup 2	9.02	4.16	2.49	-0.62	-0.73			0.052	0.016
7.5 Dup 1	9.60	5.61	6.23	-1.04	-1.25			0.262	0.266
7.5 Dup 2	9.58	2.39	5.09	-0.83	-1.45			0.154	0.109

Enterococcus Bacteria Disinfection Data for Low Chlorine Formula in Wastewater

Objective:	Quantify Enterococcus at varying doses of Fe (VI) in wastewater at 30 min contact time					
Date of Experiment:	4/2/2008					
Date read:	4/3/2008					
Conc. (mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	49	15	261.3	261.3	2.613
0	0	49	48	>2419.6	>2419.6	>2419.6
0	2	20	2	27.5	2750	27.5
0	2	17	0	20.3	2030	20.3
0	3	2	0	2	2000	20
0	3	5	0	5.2	5200	52
2	0	49	42	1299.7	1299.7	12.997
2	0	49	45	1732.9	1732.9	17.329
2	2	11	1	13.4	1340	13.4
2	2	11	1	13.4	1340	13.4
2	0	49	46	1986.3	1986.3	19.863
2	0	49	46	1986.3	1986.3	19.863
2	2	23	1	31.3	3130	31.3
2	2	13	1	16	1600	16
4	0	49	25	461.1	461.1	4.611
4	0	49	35	816.4	816.4	8.164
4	1	32	6	59.1	591	5.91
4	1	25	0	33.6	336	3.36
4	0	49	40	1119.9	1119.9	11.199
4	0	49	30	613.1	613.1	6.131
4	1	24	2	34.5	345	3.45
4	1	28	2	34.5	345	3.45
7.5	0	46	12	156.5	156.5	1.565
7.5	0	41	13	113	113	1.13
7.5	0	46	18	190.4	190.4	1.904
7.5	0	48	21	285.1	285.1	2.851
Controls						
Enterococcus	3	49	48	>2419.6	>2419600	>24196

E. Coli Disinfection Data for Low Chlorine Formula in Wastewater

Objective:	Quantify E. Coli at varying doses of Fe (VI) in wastewater at 30 min contact time					
Date of Experiment:	4/2/2008					
Date read:	4/3/2008					
Conc. (mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	49	48	>2419.6	>2419.6	>24.196
0	0	49	48	>2419.6	>2419.6	>24.196
0	2	19	1	24.6	2460	24.6
0	2	21	4	31.8	3180	31.8
0	3	6	0	6.3	6300	63
0	3	4	0	4.1	4100	41
2	0	49	48	>2419.6	>2419.6	>24.196
2	0	49	48	>2419.6	>2419.6	>24.196
2	2	9	1	10.9	1090	10.9
2	2	5	4	9.4	940	9.4
2	0	49	48	>2419.6	>2419.6	>2419.6
2	0	49	47	2419.6	2419.6	24.196
2	2	13	6	1986.3	198630	1986.3
2	2	12	3	2419.6	241960	2419.6
4	0	49	45	1732.9	1732.9	17.329
4	0	49	43	1413.6	1413.6	14.136
4	1	24	13	50.5	505	5.05
4	1	31	13	68.7	687	6.87
4	0	49	40	1119.9	1119.9	11.199
4	0	49	46	1986.3	1986.3	19.863
4	1	33	15	79.2	792	7.92
4	1	25	22	66.8	668	6.68
7.5	0	1	0	1	1	0.01
7.5	0	1	0	1	1	0.01
7.5	0	1	0	1	1	0.01
7.5	0	0	0	<1	<1	<0.01

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	3	28	38	105.2	1052	1052
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Total Coliform Disinfection Data for Low Chlorine Formula in Wastewater

Objective:	Quantify Total Coliform at varying doses of Fe (VI) in wastewater at 30 min contact time					
Date of Experiment:	4/2/2008					
Date read:	4/3/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	49	48	>2419.6	>2419.6	>24.196
0	0	49	48	>2419.6	>2419.6	>24.196
0	2	49	48	>2419.6	>2419.6	>24.196
0	2	49	46	1986.3	198630	1986.3
0	3	49	13	235.9	235900	2359
0	3	47	9	155.3	155300	1553
2	0	49	48	>2419.6	>2419.6	>24.196
2	0	49	48	>2419.6	>2419.6	>24.196
2	2	49	47	2419.6	241960	2419.6
2	2	49	45	1732.9	173290	1732.9
2	0	49	48	>2419.6	>2419.6	>24.196
2	0	49	48	>2419.6	>2419.6	>24196
2	2	49	46	1986.3	198630	1986.3
2	2	49	47	2419.6	241960	2419.6
4	0	49	48	>2419.6	>2419.6	>24.196
4	0	49	48	>2419.6	>2419.6	>24.196
4	1	49	44	1553.1	15531	155.31
4	1	49	42	1299.7	12997	129.97
4	0	49	48	>2419.6	>2419.6	>24.196
4	0	49	48	>2419.6	>2419.6	>24.196
4	1	49	46	1986.3	19863	198.63
4	1	49	46	1986.3	19863	198.63
7.5	0	19	1	24.6	24.6	0.246
7.5	0	20	2	27.5	27.5	0.275
7.5	0	21	0	26.5	26.5	0.265
7.5	0	11	1	12.2	12.2	0.122
Controls						
E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	3	28	38	105.2	1052	1052
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Heterotrophic Bacteria Disinfection Data for Low Chlorine Formula in Wastewater

Date:	4/2/2008		Colony Forming Units (CFU)				
Conc.(mg/l)	Dilution, (10^n)	Plated Dilution, (10^n)	Plate 1	Plate 2	Plate 3	Avg CFU	Avg CFU/mL
0	0	1	224	180	220	208	2080
0	2	3	8	8	13	10	9666.667
2 Dup 1	0	1	196	196	224	205	2053.333
2 Dup 1	1	2	94	192	91	126	12566.67
2 Dup 2	0	1	168	164	216	183	1826.667
2 Dup 2	1	2	112	140	115	122	12233.33
4 Dup 1	0	1	152	192	164	169	1693.333
4 Dup 1	1	2	92	63	62	72	7233.333
4 Dup 2	0	1	136	172	188	165	1653.333
4 Dup 2	1	2	71	100	77	83	8266.667
7.5 Dup 1	0	1	128	196	104	143	1426.667
7.5 Dup 2	0	1	800	352	>300	576	5760
Controls							
Open			0				
Open			0				
Closed			0				
Closed			0				
Dilution Buffer			0				
Dilution Buffer			0				

DOC Standard Curve Data for Low Chlorine Formula in Wastewater

Objective: Measure DOC of varying doses of ferrate in wastewater at 30 minute contact time.

Known Concentration of C (mg/L)	Counts	Concentration from Instrument (mg/L DOC)
0	271080	0.28
0	140734	0.15
0	132587	0.14
0	141722	0.15
0	137452	0.14
0	147382	0.15
0.5	596339	0.62
0.5	584490	0.61
0.5	546158	0.57
1	1119001	1.17
1	1130647	1.18
1	1081468	1.13
2	2017397	2.10
2	1991473	2.07
2	1964590	2.05
5	4631216	4.82
5	4633729	4.83
5	4635503	4.83
10	8952559	9.33
10	8971977	9.35
10	8903932	9.27
20	18025160	18.78
20	17860399	18.60
20	17954587	18.70
0	183586	0.19
0	126235	0.13
0	109210	0.11

DOC Data for Low Chlorine Formula in Wastewater

Sample	Counts	Concentration from Standard Curve (mg/L DOC)	Concentration from Standard Curve (mg/L DOC)
Wastewater Replicate 1	10730328	11.91	11.18
Wastewater Replicate 1	10864399	12.06	11.32
Wastewater Replicate 1	10796993	11.98	11.25
Wastewater Replicate 2	10860315	12.05	11.31
Wastewater Replicate 2	10946673	12.15	11.40
Wastewater Replicate 2	10954685	12.16	11.41
2 mg/L Fe (VI) in WW Dup 1 Rep 1	11118387	12.34	11.58
2 mg/L Fe (VI) in WW Dup 1 Rep 1	11032769	12.25	11.49
2 mg/L Fe (VI) in WW Dup 1 Rep 1	10996560	12.21	11.45
2 mg/L Fe (VI) in WW Dup 1 Rep 2	11017759	12.23	11.48
2 mg/L Fe (VI) in WW Dup 1 Rep 2	10995423	12.20	11.45
2 mg/L Fe (VI) in WW Dup 1 Rep 2	11028207	12.24	11.49
2 mg/L Fe (VI) in WW Dup 2 Rep 1	10621549	11.78	11.06
2 mg/L Fe (VI) in WW Dup 2 Rep 1	10630225	11.79	11.07
2 mg/L Fe (VI) in WW Dup 2 Rep 1	10734294	11.91	11.18
2 mg/L Fe (VI) in WW Dup 2 Rep 2	10690400	11.86	11.14
2 mg/L Fe (VI) in WW Dup 2 Rep 2	10671224	11.84	11.12
2 mg/L Fe (VI) in WW Dup 2 Rep 2	10606657	11.77	11.05
4 mg/L Fe (VI) in WW Dup 1 Rep 1	10390982	11.52	10.82
4 mg/L Fe (VI) in WW Dup 1 Rep 1	10328612	11.45	10.76
4 mg/L Fe (VI) in WW Dup 1 Rep 1	10505866	11.65	10.94
4 mg/L Fe (VI) in WW Dup 1 Rep 2	10376997	11.51	10.81
4 mg/L Fe (VI) in WW Dup 1 Rep 2	10437908	11.58	10.87
4 mg/L Fe (VI) in WW Dup 1 Rep 2	10296585	11.42	10.73
4 mg/L Fe (VI) in WW Dup 2 Rep 1	11014151	12.23	11.47
4 mg/L Fe (VI) in WW Dup 2 Rep 1	11056047	12.27	11.52
4 mg/L Fe (VI) in WW Dup 2 Rep 1	10926765	12.13	11.38
4 mg/L Fe (VI) in WW Dup 2 Rep 2	10817329	12.00	11.27
4 mg/L Fe (VI) in WW Dup 2 Rep 2	10866142	12.06	11.32
4 mg/L Fe (VI) in WW Dup 2 Rep 2	10953728	12.16	11.41
7.5 mg/L Fe (VI) in WW Dup 1 Rep 1	10345191	11.47	10.78
7.5 mg/L Fe (VI) in WW Dup 1 Rep 1	10485943	11.63	10.92
7.5 mg/L Fe (VI) in WW Dup 1 Rep 1	10364184	11.49	10.80
7.5 mg/L Fe (VI) in WW Dup 1 Rep 2	10399143	11.53	10.83
7.5 mg/L Fe (VI) in WW Dup 1 Rep 2	10222042	11.33	10.65
7.5 mg/L Fe (VI) in WW Dup 1 Rep 2	10370903	11.50	10.80
7.5 mg/L Fe (VI) in WW Dup 2 Rep 1	10223653	11.33	10.65
7.5 mg/L Fe (VI) in WW Dup 2 Rep 1	10161927	11.26	10.59
7.5 mg/L Fe (VI) in WW Dup 2 Rep 1	10123458	11.22	10.55
7.5 mg/L Fe (VI) in WW Dup 2 Rep 2	10053625	11.14	10.47
7.5 mg/L Fe (VI) in WW Dup 2 Rep 2	10067951	11.16	10.49
7.5 mg/L Fe (VI) in WW Dup 2 Rep 2	10186766	11.29	10.61

C-4 River Water Data

Enterococcus Bacteria Disinfection Calculations in River Water

Enterococcus Bacteria For Standard Formula

Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Conc.(mg/l)	Standard Deviation	Mean+stdev	Mean-stdev	log removal
	0	5.2						
0	0	4.1	4.65	0.00	0.78	5.43	3.87	N/A
	0	1						
	0	1						
	0	1						
2	0	1	1.00	2.00	0.00	1.00	1.00	0.67
	0	1						
	0	1						
	0	1						
4	0	1	1.00	4.00	0.00	1.00	1.00	0.67
	0	1						
	0	1						
	0	1						
7.5	0	1	1.00	7.50	0.00	1.00	1.00	0.67

Enterococcus Bacteria For Low Chlorine Formula

Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Conc.(mg/l)	Standard Deviation	Mean+stdev	Mean-stdev	log removal
	0	12.2						
0	0	8.5	10.35	0.00	2.62	12.97	7.73	N/A
	0	5.2						
	0	9.8						
	0	8.6						
2	0	3.1	6.68	2.00	3.08	9.75	3.60	0.19
	0	1						
	0	1						
	0	1						
4	0	3.1	1.53	4.00	1.05	2.58	0.47	0.83
	0	1						
	0	1						
	0	1						
7.5	0	1	1.00	7.50	0.00	1.00	1.00	1.01

E. Coli Disinfection Calculations in River Water

E. Coli Bacteria For Standard Formula

Conc.(mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	log removal
	0	1					
0-B	0	1	1.00	0.00	1.00	1.00	n/A
	0	1					
	0	1					
	0	1					
2-B	0	1	1.00	0.00	1.00	1.00	0.00
	0	1					
	0	1					
	0	1					
4-B	0	1	1.00	0.00	1.00	1.00	0.00
	0	1					
	0	1					
	0	1					
7.5-B	0	1	1.00	0.00	1.00	1.00	0.00

E. Coli Bacteria For Low Chlorine Formula

Conc.(mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	log removal
	0	8.6					
0-A	0	8.6	8.60	0.00	8.60	8.60	N/A
	0	1					
	0	1					
	0	1					
2-A	0	1	1.00	0.00	1.00	1.00	0.93
	0	1					
	0	1					
	0	1					
4-A	0	1	1.00	0.00	1.00	1.00	0.93
	0	1					
	0	1					
	0	1					
7.5-A	0	1	1.00	0.00	1.00	1.00	0.93

E. Coli Disinfection Calculations in River Water

Total Coliform Bacteria For Standard Formula							
Conc. (mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	Log removal
	0	2419.6					
	0	1299.7					
	1	253					
0-B	1	120	1023.08	1070.10	2093.18	-47.03	N/A
	0	1					
	0	1					
	0	1					
2-B	0	1	1.00	0.00	1.00	1.00	3.01
	0	1					
	0	1					
	0	1					
4-B	0	1	1.00	0.00	1.00	1.00	3.01
	0	1					
	0	1					
	0	1					
7.5-B	0	1	1.00	0.00	1.00	1.00	3.01

Total Coliform Bacteria For Low Chlorine Formula							
Conc.(mg/l)	Dilution	MPN/100ml Accounting for Dilution	Mean	Standard Deviation	Mean+stdev	Mean-stdev	Log removal
	0	186					
0-A	0	137.4	161.70	34.37	196.07	127.33	N/A
	0	5.2					
	0	1					
	0	4.1					
2-A	0	3	3.33	1.79	5.12	1.53	1.69
	0	1					
	0	1					
	0	1					
4-A	0	1	1.00	0.00	1.00	1.00	2.21
	0	1					
	0	1					
	0	1					
7.5-A	0	1	1.00	0.00	1.00	1.00	2.21

Heterotrophic Bacteria Disinfection Calculations for Standard Formula in River Water

Conc. (mg/)	Plated Dilution, (10^n)	CFU/ml	CFU/mL accounting for dilution	Mean	Standard Deviation	Mean+ stdev	Mean- stdev	Log removal
	1	364	3640					
	1	356	3560					
	1	360	3600					
	2	180	18000					
	2	188	18800					
0-B	2	124	12400	10000 .00	7349.60	17349.60	2650.40	N/A
	1	4	40					
	1	7	70					
	1	2	20					
	1	6	60					
	1	7	70					
	1	1	10					
	0	45	45					
	0	32	32					
	0	42	42					
	0	19	19					
	0	35	35					
2-B	0	30	30	39.42	19.44	58.85	19.98	2.40
	1	8	80					
	1	4	40					
	1	3	30					
	1	5	50					
	1	13	130					
	1	5	50					
	0	18	18					
	0	22	22					
	0	22	22					
	0	17	17					
	0	61	61					
4-B	0	13	13	44.42	33.84	78.26	10.58	2.35
	1	4	40					
	1	3	30					
	1	4	40					
	1	4	40					
	1	6	60					
	1	4	40					
	0	35	35					
	0	31	31					
	0	30	30					
	0	52	52					
	0	40	40					
7.5-B	0	32	32	39.17	9.07	48.24	30.09	2.41

Heterotrophic Bacteria Disinfection Calculations for Low Chlorine Formula in River Water

Conc. (mg/l)	Plated Dilution, (10^n)	CFU/ ml	CFU/mL accounting for dilution	Mean	Standard Deviation	Mean+ stdev	Mean- stdev	Log removal
	1	257	2570					
	1	236	2360					
	1	604	6040					
	2	140	14000					
	2	188	18800					
0-A	2	124	12400	9361.67	6723.26	16084.93	2638.40	N/A
	1	9	90					
	1	17	170					
	1	14	140					
	1	14	140					
	1	22	220					
	1	8	80					
	0	65	65					
	0	95	95					
	0	70	70					
	0	63	63					
	0	100	100					
2-A	0	40	40	106.08	51.94	158.02	54.14	1.95
	1	6	60					
	1	6	60					
	1	5	50					
	1	7	70					
	1	10	100					
	1	6	60					
	0	9	9					
	0	18	18					
	0	17	17					
	0	14	14					
	0	9	9					
4-A	0	16	16	40.25	30.13	70.38	10.12	2.37
	1	2	20					
	1	4	40					
	1	0	0					
	1	2	20					
	1	4	40					
	1	11	110					
	0	19	19					
	0	34	34					
	0	72	72					
	0	25	25					
	0	43	43					
7.5-A	0	36	36	38.25	28.63	66.88	9.62	2.39

Standard Formula Data

Enterococcus Bacteria Disinfection Data for Standard Formula in River Water

Objective:	Quantify Enterococcus at varying doses of Fe (VI) in River water at 30 min contact time					
Date of Experiment:	4/16/2008					
Date read:	4/17/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	4	1	5.2	5.2	0.052
0	0	4	0	4.1	4.1	0.041
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	1	0	1	1	0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
Controls						
Enterococcus	3	49	48	>2419.6	>2419600	>24196

E. Coli Disinfection Data for Standard Formula in River Water

Objective:	Quantify E. Coli at varying doses of Fe (VI) in River water at 30 min contact time
Date of Experiment:	4/16/2008
Date read:	4/17/2008

Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	0	0	<1	<1	<0.01
0	0	0	0	<1	<1	<0.01
0	1	0	0	<1	<0.1	<0.001
0	1	0	0	<1	<0.1	<0.001
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	1	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	2	49	48	>2419.7	>241960	>2419.7
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Total Coliform Disinfection Data for Standard Formula in River Water

Objective:	Quantify Total Coliform at varying doses of Fe (VI) in River water at 30 min contact time					
Date of Experiment:	4/16/2008					
Date read:	4/17/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	MPN/ml
0	0	49	48	>2419.6	>2419.6	>24.2
0	0	49	42	1299.7	1299.7	12.997
0	1	17	4	25.3	253	2.53
0	1	9	2	12	120	1.2
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	2	49	48	>2419.6	>241960	>2419.6
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Heterotrophic Bacteria Disinfection Data for Standard Formula in River Water

			Colony Forming Units (CFU)				
Conc.(mg/l)	Dilution, (10^n)	Plated Dilution (10^n)	Plate 1	Plate 2	Plate 3	Avg CFU	Accounting for Plated Dilution Avg CFU/mL
0	0	1	364	356	360	360	3600.00
2 Dup 1	0	1	4	7	2	4	43.33
2 Dup 2	0	1	6	7	1	5	46.67
4 Dup 1	0	1	8	4	3	5	50.00
4 Dup 2	0	1	5	13	5	8	76.67
7.5 Dup 1	0	1	4	3	4	4	36.67
7.5 Dup 2	0	1	4	6	4	5	46.67
Controls							
Open			0				
Open			0				
Closed			0				
Closed			0				
Conc.(mg/l)	Dilution, (10^n)	Plated Dilution (10^n)	Plate 1	Plate 2	Plate 3	Avg CFU	Accounting for Plated Dilution Avg CFU/mL
0	1	2	180	188	124	164	16400.00
2 Dup 1	0	0	45	32	42	40	39.67
2 Dup 2	0	0	19	35	30	28	28.00
4 Dup 1	0	0	18	22	22	21	20.67
4 Dup 2	0	0	17	61	13	30	30.33
7.5 Dup 1	0	0	35	31	30	32	32.00
7.5 Dup 2	0	0	52	40	34	42	42.00
Controls							
Open			0	0			
Closed			0	0			
Dilution Buffer	0	1	0	0			

DOC Standard Curve Data for Standard Formula in River Water

Objective: Measure DOC of varying doses of ferrate in wastewater at 30 minute contact time.

Known Concentration of C (mg/L)	Counts	Concentration from Instrument (mg/L DOC)
0	229261	0.24
0	150228	0.16
0	153792	0.16
0	160293	0.17
0	167771	0.17
0	287783	0.30
0.5	748404	0.78
0.5	732106	0.76
0.5	705898	0.74
1	1137284	1.18
1	1143384	1.19
1	1132865	1.18
2	2116486	2.20
2	2097883	2.19
2	2121053	2.21
5	4762568	4.96
5	4766046	4.96
5	4803861	5.00
10	9239623	9.62
10	9238312	9.62
10	9386509	9.78
20	18898541	19.69
20	18860113	19.65
20	19025962	19.82

DOC Data for Standard Formula in River Water

Sample	Counts	Concentration from DOC Instrument (mg/L DOC)	Concentration from Standard Curve (mg/L DOC)
Econ River water Replicate 1	13689817	14.26	14.50
Econ River water Replicate 1	13940225	14.52	14.77
Econ River water Replicate 1	14043003	14.63	14.88
Econ River water Replicate 2	14049599	14.64	14.88
Econ River water Replicate 2	14086535	14.67	14.92
Econ River water Replicate 2	14053796	14.64	14.89
2 mg/L Fe (VI) in River Water Dup 1 Rep 1	14186325	14.78	15.03
2 mg/L Fe (VI) in River Water Dup 1 Rep 1	14019501	14.60	14.85
2 mg/L Fe (VI) in River Water Dup 1 Rep 1	13977484	14.56	14.81
2 mg/L Fe (VI) in River Water Dup 1 Rep 2	13921726	14.50	14.75
2 mg/L Fe (VI) in River Water Dup 1 Rep 2	13863438	14.44	14.68
2 mg/L Fe (VI) in River Water Dup 1 Rep 2	14038965	14.62	14.87
2 mg/L Fe (VI) in River Water Dup 2 Rep 1	13778845	14.35	14.59
2 mg/L Fe (VI) in River Water Dup 2 Rep 1	13742457	14.32	14.55
2 mg/L Fe (VI) in River Water Dup 2 Rep 1	13885858	14.46	14.71
2 mg/L Fe (VI) in River Water Dup 2 Rep 2	13837744	14.41	14.66
2 mg/L Fe (VI) in River Water Dup 2 Rep 2	13789574	14.36	14.60
2 mg/L Fe (VI) in River Water Dup 2 Rep 2	13868158	14.45	14.69
4 mg/L Fe (VI) in River Water Dup 1 Rep 1	13527924	14.09	14.32
4 mg/L Fe (VI) in River Water Dup 1 Rep 1	13577264	14.14	14.38
4 mg/L Fe (VI) in River Water Dup 1 Rep 1	13453613	14.01	14.24
4 mg/L Fe (VI) in River Water Dup 1 Rep 2	13512220	14.08	14.31
4 mg/L Fe (VI) in River Water Dup 1 Rep 2	13477622	14.04	14.27
4 mg/L Fe (VI) in River Water Dup 1 Rep 2	13436274	14.00	14.23
4 mg/L Fe (VI) in River Water Dup 2 Rep 1	13381422	13.94	14.17
4 mg/L Fe (VI) in River Water Dup 2 Rep 1	13397456	13.96	14.18
4 mg/L Fe (VI) in River Water Dup 2 Rep 1	13446562	14.01	14.24
4 mg/L Fe (VI) in River Water Dup 2 Rep 2	13545224	14.11	14.34
4 mg/L Fe (VI) in River Water Dup 2 Rep 2	13557143	14.12	14.36
4 mg/L Fe (VI) in River Water Dup 2 Rep 2	13712271	14.28	14.52
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 1	10693943	11.14	11.28
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 1	10583591	11.02	11.16
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 1	10562304	11.00	11.14
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 2	10768245	11.22	11.36
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 2	10662588	11.11	11.25
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 2	10659807	11.10	11.24
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 1	11267047	11.74	11.90
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 1	11249281	11.72	11.88
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 1	11407762	11.88	12.05
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 2	11382758	11.86	12.02
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 2	11260005	11.73	11.89
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 2	11285607	11.76	11.92

Date: 4/15/2008

Objective:

Measure ferrate, total oxidant, and total chlorine of Formula B Ferrate in Econ River water at 30 minutes

Spectrasuite

Zero-DI water		Absorbance
River Water		0.019
Filtered River Water		0.011

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.002
River Water with DPD	0.041
Filtered River water with DPD	0.037
Blank Gel	0.076
Std. 1	0.172
Std. 2	0.510
Std. 3	0.857

Chlorine Standard Curve with respect to filtered wastewater with DPD		
Sample	Abs	Known Concentration
Std. 1	0.135	0.18
Std. 2	0.473	0.82
Std. 3	0.820	1.47

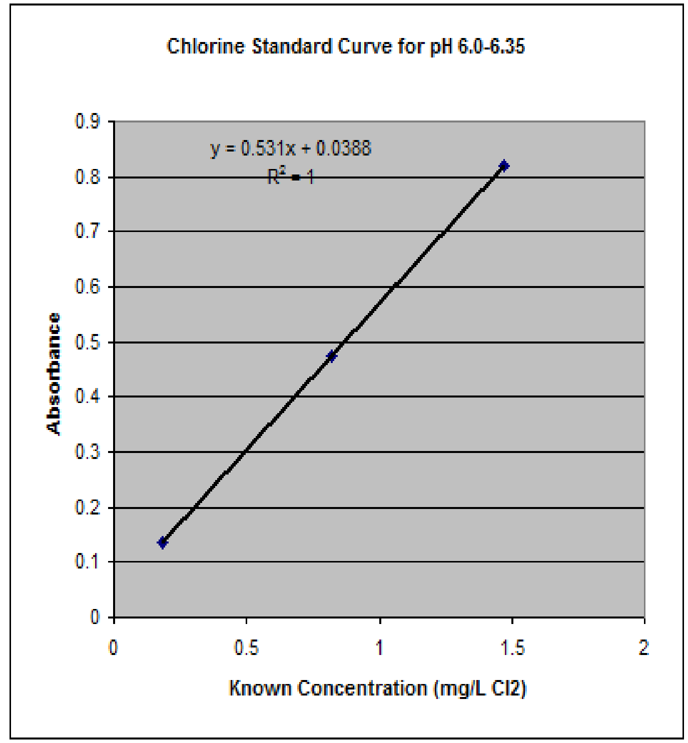


Table 1: Raw Data

		Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH		HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
Ferrate Concentration (mg/L) in WW	pH	Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 2 Filtered	Replicate 2 Filtered	Replicate 1 Absorbance	Replicate 2 Absorbance	Replicate 1 Absorbance	Replicate 2 Absorbance
2 Dup 1	9.95	0.015	0.014	0.011	0.009	0.124	0.123	0.063	0.042
2 Dup 2	10.00	0.016	0.015	0.008	0.009	0.118	0.120	0.055	0.045
4 Dup 1	10.79	0.040	0.038	0.015	0.009	0.225	0.216	0.094	0.110
4 Dup 2	10.73	0.041	0.042	0.010	0.011	0.279	0.246	0.113	0.126
7.5 Dup 1	11.26	0.089	0.091	0.006	0.010	0.728	0.861	0.535	0.632
7.5 Dup 2	11.23	0.080	0.081	0.006	0.005	0.465	0.464	0.119	0.110

Table 2: Absorbances for River Water

		Ferrate Absorbance Adjusted for River water at 510nm				HACH DPD Total Chlorine with respect to Filtered River water with DPD at 530 nm		HACH DPD Total Chlorine with respect to Filtered River water with DPD at 530 nm, ph 6.0-6.35	
Ferrate Concentration (mg/L) in WW	pH	Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 1 Filtered	Replicate 2 Filtered	Replicate 1 Absorbance	Replicate 2 Absorbance	Replicate 1 Absorbance	Replicate 2 Absorbance
2 Dup 1	9.95	-0.004	-0.005	0.000	-0.002	0.087	0.086	0.026	0.005
2 Dup 2	10.00	-0.003	-0.004	-0.003	-0.002	0.081	0.083	0.018	0.008
4 Dup 1	10.79	0.021	0.019	0.004	-0.002	0.188	0.179	0.057	0.073
4 Dup 2	10.73	0.022	0.023	-0.001	0.000	0.242	0.209	0.076	0.089
7.5 Dup 1	11.26	0.070	0.072	-0.005	-0.001	0.691	0.824	0.498	0.595
7.5 Dup 2	11.23	0.061	0.062	-0.005	-0.006	0.428	0.427	0.082	0.073

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm						HACH DPD Total Chlorine with respect to Filtered River water with DPD at 530 nm, ph 6.0-6.35	
Ferrate Concentration (mg/L) in WW	pH	Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 1 Filtered	Replicate 2 Filtered			Replicate 1 Concentration (mg/L Cl2)	Replicate 2 Concentration (mg/L Cl2)
2 Dup 1	9.95	-0.42	-0.52	0.00	-0.21			-0.024	-0.064
2 Dup 2	10.00	-0.31	-0.42	-0.31	-0.21			-0.039	-0.058
4 Dup 1	10.79	2.18	1.97	0.42	-0.21			0.034	0.064
4 Dup 2	10.73	2.29	2.39	-0.10	0.00			0.070	0.095
7.5 Dup 1	11.26	7.27	7.48	-0.52	-0.10			0.865	1.047
7.5 Dup 2	11.23	6.34	6.44	-0.52	-0.62			0.081	0.064

Low Chlorine Formula

Enterococcus Bacteria Disinfection Data for Low Chlorine Formula in River Water

Objective:	Quantify Enterococcus at varying doses of Fe (VI) in River water at 30 min contact time					
Date of Experiment:	4/16/2008					
Date read:	4/17/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	11	0	12.2	12.2	0.122
0	0	7	1	8.5	8.5	0.085
2	0	5	0	5.2	5.2	0.052
2	0	9	0	9.8	9.8	0.098
2	0	8	0	8.6	8.6	0.086
2	0	3	0	3.1	3.1	0.031
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	3	0	3.1	3.1	0.031
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
Controls						
Enterococcus	3	49	48	>2419.6	>2419600	>24196

E. Coli Disinfection Data for Low Chlorine Formula in River Water

Objective:	Quantify E. Coli at varying doses of Fe (VI) in River water at 30 min contact time					
Date of Experiment:	4/16/2008					
Date read:	4/17/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	8	0	8.6	8.6	0.086
0	0	8	0	8.6	8.6	0.086
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
2	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	2	49	48	>2419.7	>241960	>2419.7
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Total Coliform Disinfection Data for Low Chlorine Formula in River Water

Objective:	Quantify Total Coliform at varying doses of Fe (VI) in River water at 30 min contact time					
Date of Experiment:	4/16/2008					
Date read:	4/17/2008					
Conc.(mg/l)	Dilution	Positive Large wells	Positive Small wells	MPN/100ml	MPN/100ml Accounting for Dilution	Calculated MPN/mL
0	0	48	11	186	186	1.86
0	0	44	13	137.4	137.4	1.374
2	0	5	0	5.2	5.2	0.052
2	0	0	0	<1	<1	<0.01
2	0	4	0	4.1	4.1	0.041
2	0	1	2	3	3	0.03
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
4	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01
7.5	0	0	0	<1	<1	<0.01

Controls

E. Coli	3	49	48	>2419.6	>2419600	>24196
Klebsiella pneumoniae	2	49	48	>2419.7	>241960	>2419.7
Pseudomonas aeruginosa	3	0	0	<1	<1000	<10
Dilution Buffer	0	0	0	<1	<1	<0.01

Heterotrophic Bacteria Disinfection Data for Low Chlorine Formula in River Water

			Colony Forming Units (CFU)				
Conc.(mg/l)	Dilution, (10^n)	Plated Dilution (10^n)	Plate 1	Plate 2	Plate 3	Avg CFU	Avg CFU/mL
0	0	1	256	236	604	365	3653.33
2 Dup 1	0	1	9	17	14	13	133.33
2 Dup 2	0	1	14	22	8	15	146.67
4 Dup 1	0	1	6	6	5	6	56.67
4 Dup 2	0	1	7	10	6	8	76.67
7.5 Dup 1	0	1	2	4	0	2	20.00
7.5 Dup 2	0	1	2	4	11	6	56.67
Controls							
Open			0				
Open			0				
Closed			0				
Closed			0				
Conc.(mg/l)	Dilution, (10^n)	Plated Dilution (10^n)	Plate 1	Plate 2	Plate 3	Avg CFU	Avg CFU/mL
0	1	2	140	188	124	151	15066.67
2 Dup 1	0	0	65	95	70	77	76.67
2 Dup 2	0	0	63	100	40	68	67.67
4 Dup 1	0	0	9	18	17	15	14.67
4 Dup 2	0	0	14	9	16	13	13.00
7.5 Dup 1	0	0	19	34	72	42	41.67
7.5 Dup 2	0	0	25	43	36	35	34.67
Controls							
Open			0				
Open			0				
Closed			0				
Closed			0				
Dilution Buffer			0				
Dilution Buffer			0				

DOC Standard Curve Data for Low Chlorine Formula in River Water

Objective: Measure DOC of varying doses of ferrate in wastewater at 30 minute contact time.

Known Concentration of C (mg/L)	Counts	Concentration from Instrument (mg/L DOC)
0	229261	0.24
0	150228	0.16
0	153792	0.16
0	160293	0.17
0	167771	0.17
0	287783	0.30
0.5	748404	0.78
0.5	732106	0.76
0.5	705898	0.74
1	1137284	1.18
1	1143384	1.19
1	1132865	1.18
2	2116486	2.20
2	2097883	2.19
2	2121053	2.21
5	4762568	4.96
5	4766046	4.96
5	4803861	5.00
10	9239623	9.62
10	9238312	9.62
10	9386509	9.78
20	18898541	19.69
20	18860113	19.65
20	19025962	19.82

DOC Data for Low Chlorine Formula in River Water

Sample	Counts	Concentration from DOC Instrument (mg/L DOC)	Concentration from Standard Curve (mg/L DOC)
Econ River water Replicate 1	12241424	12.7515	12.94
Econ River water Replicate 1	12220448	12.7296	12.92
Econ River water Replicate 1	12191515	12.6995	12.89
Econ River water Replicate 2	12744138	13.2751	13.48
Econ River water Replicate 2	12678240	13.2065	13.41
Econ River water Replicate 2	12677280	13.2055	13.41
2 mg/L Fe (VI) in River Water Dup 1 Rep 1	12128214	12.6336	12.82
2 mg/L Fe (VI) in River Water Dup 1 Rep 1	11910863	12.4071	12.59
2 mg/L Fe (VI) in River Water Dup 1 Rep 1	11940155	12.4377	12.62
2 mg/L Fe (VI) in River Water Dup 1 Rep 2	11994387	12.4942	12.68
2 mg/L Fe (VI) in River Water Dup 1 Rep 2	11930242	12.4273	12.61
2 mg/L Fe (VI) in River Water Dup 1 Rep 2	11991273	12.4909	12.67
2 mg/L Fe (VI) in River Water Dup 2 Rep 1	12005403	12.5056	12.69
2 mg/L Fe (VI) in River Water Dup 2 Rep 1	12002375	12.5025	12.69
2 mg/L Fe (VI) in River Water Dup 2 Rep 1	11964736	12.4633	12.65
2 mg/L Fe (VI) in River Water Dup 2 Rep 2	12009851	12.5103	12.69
2 mg/L Fe (VI) in River Water Dup 2 Rep 2	12202621	12.7111	12.90
2 mg/L Fe (VI) in River Water Dup 2 Rep 2	11996717	12.4966	12.68
4 mg/L Fe (VI) in River Water Dup 1 Rep 1	11658467	12.1442	12.32
4 mg/L Fe (VI) in River Water Dup 1 Rep 1	11471911	11.9499	12.12
4 mg/L Fe (VI) in River Water Dup 1 Rep 1	11607509	12.0912	12.26
4 mg/L Fe (VI) in River Water Dup 1 Rep 2	11550912	12.0322	12.20
4 mg/L Fe (VI) in River Water Dup 1 Rep 2	11515703	11.9955	12.16
4 mg/L Fe (VI) in River Water Dup 1 Rep 2	11561186	12.0429	12.21
4 mg/L Fe (VI) in River Water Dup 2 Rep 1	11904424	12.4004	12.58
4 mg/L Fe (VI) in River Water Dup 2 Rep 1	11882519	12.3776	12.56
4 mg/L Fe (VI) in River Water Dup 2 Rep 1	12021716	12.5226	12.71
4 mg/L Fe (VI) in River Water Dup 2 Rep 2	12021730	12.5226	12.71
4 mg/L Fe (VI) in River Water Dup 2 Rep 2	11939360	12.4368	12.62
4 mg/L Fe (VI) in River Water Dup 2 Rep 2	11919248	12.4159	12.60
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 1	9749820	10.1561	10.27
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 1	9714468	10.1192	10.23
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 1	9669789	10.0727	10.18
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 2	9471117	9.8657	9.97
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 2	9449170	9.8429	9.94
7.5 mg/L Fe (VI) in River Water Dup 1 Rep 2	9534330	9.9316	10.04
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 1	10004863	10.4217	10.54
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 1	9956515	10.3714	10.49
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 1	9915812	10.329	10.45
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 2	9968686	10.384	10.50
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 2	9968694	10.3841	10.50
7.5 mg/L Fe (VI) in River Water Dup 2 Rep 2	9951083	10.3657	10.48

Date: 4/15/2008

Objective: Measure ferrate, total oxidant, and total chlorine of Formula A Ferrate in Econ River water at 30 minutes

Spectrasuite

Zero-DI water		Absorbance
River Water		0.019
Filtered River Water		0.011

Hach Spectrophotometer Setup

Zero on Di water	
Di with DPD	0.002
River Water with DPD	0.041
Filtered River water with DPD	0.037
Blank Gel	0.076
Std. 1	0.172
Std. 2	0.510
Std. 3	0.857

Chlorine Standard Curve with respect to filtered wastewater with DPD

Sample	Abs	Known Concentration
Std. 1	0.135	0.18
Std. 2	0.473	0.82
Std. 3	0.820	1.47

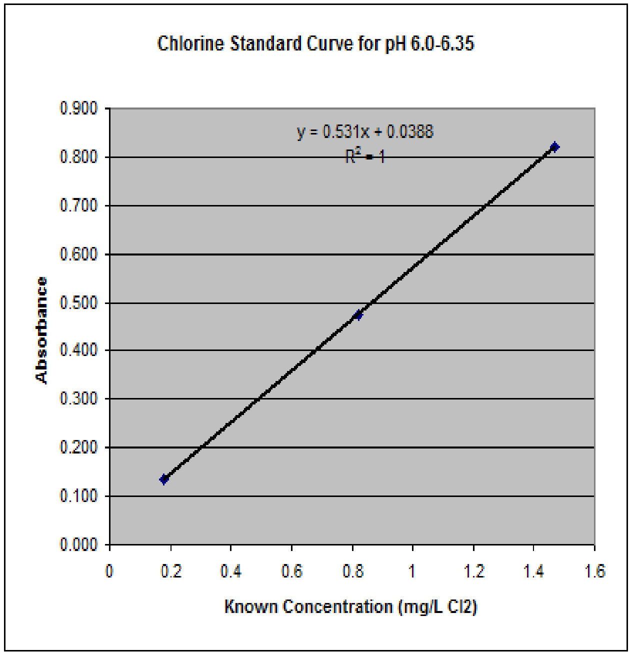


Table 1: Raw Data

Ferrate Concentration (mg/L) in WW	pH	Ferrate Absorbance based on DI water as zero at 510nm Unadjusted pH				HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at unadjusted pH		HACH DPD Total Chlorine with respect to DI with DPD at 530 nm at pH 6-6.35	
		Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 2 Filtered	Replicate 2 Filtered	Replicate 1 Absorbance	Replicate 2 Absorbance	Replicate 1 Absorbance	Replicate 2 Absorbance
2 Dup 1	10.20	0.035	0.034	0.006	0.011	0.073	0.071	0.045	0.044
2 Dup 2	10.30	0.034	0.037	0.088	0.010	0.063	0.065	0.041	0.038
4 Dup 1	10.93	0.068	0.064	0.010	0.010	0.148	0.171	0.053	0.058
4 Dup 2	10.88	0.070	0.075	0.008	0.009	0.142	0.175	0.056	0.069
7.5 Dup 1	11.23	0.110	0.111	0.007	0.009	0.360	0.310	0.035	0.063
7.5 Dup 2	11.23	0.135	0.135	0.017	0.017	0.292	0.322	0.055	0.047

Table 2: Absorbances for River Water

Ferrate Concentration (mg/L) in WW	pH	Ferrate Absorbance Adjusted for River water at 510nm				HACH DPD Total Chlorine with respect to Filtered River water with DPD at 530 nm		HACH DPD Total Chlorine with respect to Filtered River water with DPD at 530 nm, ph 6.0-6.35	
		Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replicate 1 Filtered	Replicate 2 Filtered	Replicate 1 Absorbance	Replicate 2 Absorbance	Replicate 1 Absorbance	Replicate 2 Absorbance
2 Dup 1	8.81	0.016	0.015	-0.005	0.000	0.036	0.034	0.008	0.007
2 Dup 2	8.72	0.015	0.018	0.077	-0.001	0.026	0.028	0.004	0.001
4 Dup 1	9.05	0.049	0.045	-0.001	-0.001	0.111	0.134	0.016	0.021
4 Dup 2	9.02	0.051	0.056	-0.003	-0.002	0.105	0.138	0.019	0.032
7.5 Dup 1	9.60	0.091	0.092	-0.004	-0.002	0.323	0.273	-0.002	0.026
7.5 Dup 2	9.58	0.116	0.116	0.006	0.006	0.255	0.285	0.018	0.010

Table 3: Concentrations using Adjusted Information

		Ferrate Concentration (mg/L) at 510nm						HACH DPD Total Chlorine with respect to Filtered River water with DPD at 530 nm, ph 6.0-6.35	
Ferrate Concentration (mg/L) in WW	pH	Replicate 1 Unfiltered	Replicate 2 UnFiltered	Replica te 1 Filtered	Replicate 2 Filtered			Replicate 1 Concentration (mg/L Cl2)	Replicate 2 Concentratio n (mg/L Cl2)
2 Dup 1	8.81	1.66	1.56	-0.52	0.00			-0.058	-0.060
2 Dup 2	8.72	1.56	1.87	8.00	-0.10			-0.066	-0.071
4 Dup 1	9.05	5.09	4.68	-0.10	-0.10			-0.043	-0.034
4 Dup 2	9.02	5.30	5.82	-0.31	-0.21			-0.037	-0.013
7.5 Dup 1	9.60	9.46	9.56	-0.42	-0.21			-0.077	-0.024
7.5 Dup 2	9.58	12.05	12.05	0.62	0.62			-0.039	-0.054

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